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SEP 73 D E RITCHIE, T S KOO DACW61-71-C-0062
UNCLASSIFIED NRI-REF-74-42 NL

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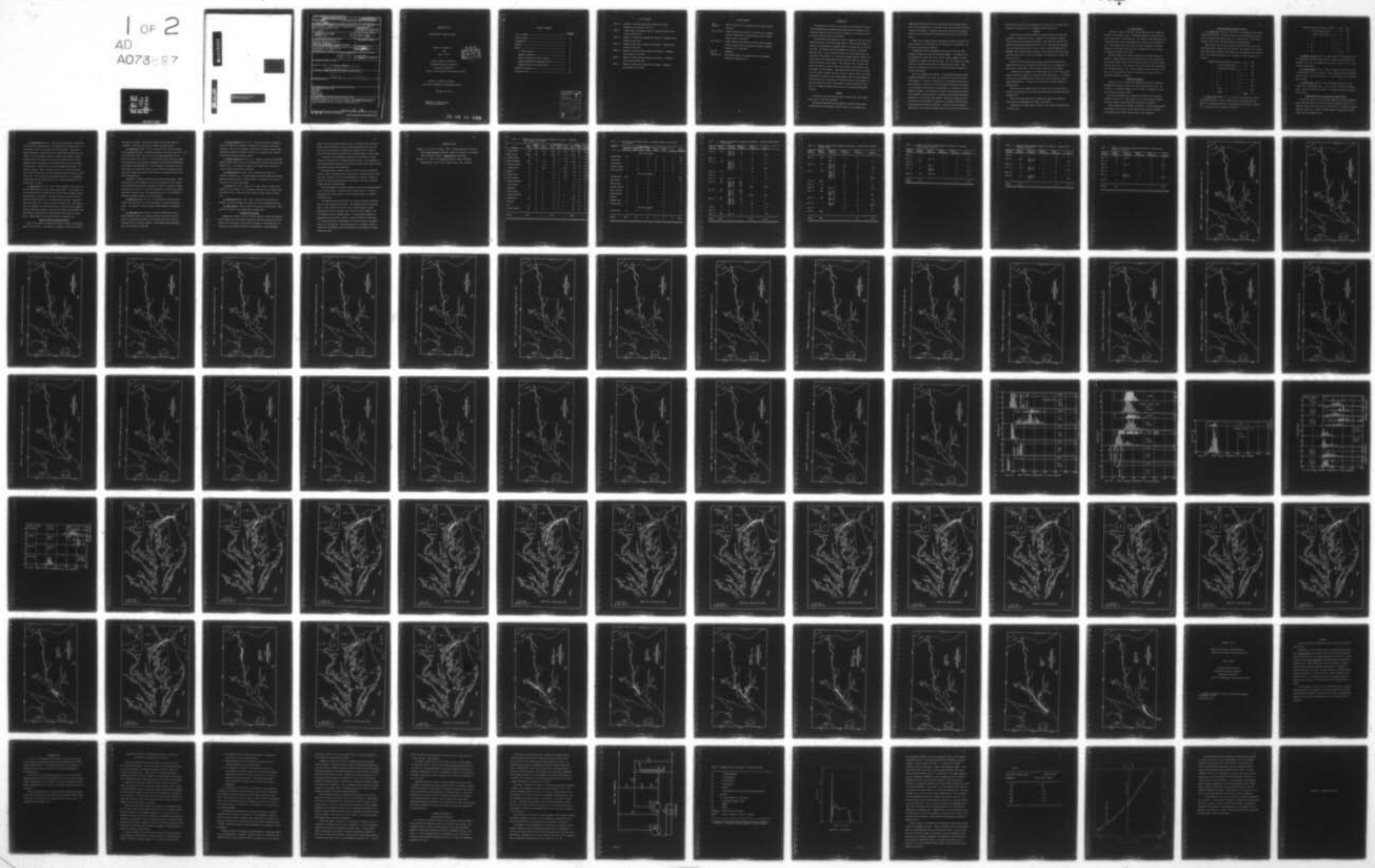

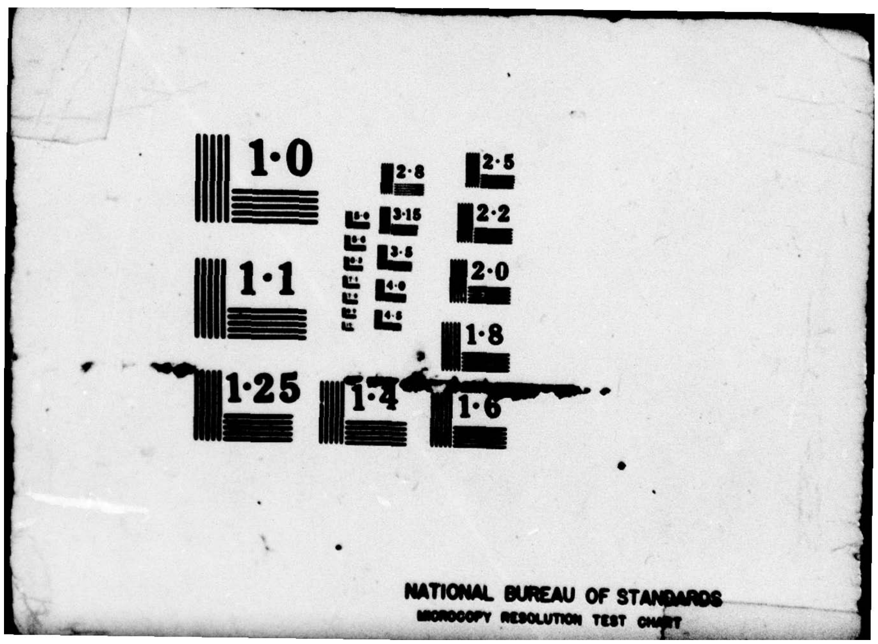
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~~This was~~ is given a summary of the results of a massive fish tagging operation in the C & D canal region in 1971-73, Direct evidence was found that fish either migrate back and forth thru the canal or move within in.

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APPENDIX VIII-A

Fish Movements - Maryland Study

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INTRODUCTION

The purpose of this report is to summarize the results of a massive fish tagging operation conducted concurrently with our cooperator, the biological group from the University of Delaware, to evaluate the use of the C and D Canal by fish in that region.

No information existed upon the close-in tagging of fish done in the Maryland portion of the C and D Canal region. Tags had been applied in the past to striped bass and American shad in the upper Bay not far from the Canal. The American shad was documented in its use of the Canal (Whitney, 1961). Also, information exists that shows striped bass use the Canal in its migration tc and from the spawning grounds (Nichols and Miller, 1967), but these workers did not tag their fish near the Canal and did not tag any other species. This work was done to provide additional information. Species found to be abundant in the Maryland area were tagged in large numbers. Some species were few in number, but they were also tagged in hope of possible returns. However, only a few of the large number of young spot were tagged because they are below commercial size and the chance of getting any recoveries would be very limited. On the other hand, we did tag a large number of small white perch, since this is a resident species and they may offer long-term recovery possibilities.

METHODS

Two kinds of tags were used to mark the fish in the C and D Canal study area in 1971, 1972, and 1973.

The CBL-modified Carlin tag was applied to small fish less than 1 foot (254 mm) in fork length. Fish 12 inches F.L. and larger were

tagged with the Petersen disc tag. The Carlin tag was orange colored. One of the 2 Petersen discs was orange and the other was white with black printed return address. Stainless steel wires were used for attaching Carlin tags, and a seawater corrosion proof pin was used to fasten the discs.

While fish of various species were marked at several locations, the main release site for most fish was at Turkey Point in the mouth of the Elk River, Cecil County, Maryland.

Considerable effort was expended in all years to retrieve from Maryland fishermen any tags they might have caught. The legend on the tag informed the reader who we are, why the fish was tagged, and what information we needed concerning his catch. Also, our address and reward 'alert' was imprinted along with the individual tag's number. Hence, tags were returned from out-of-state locations with good information in all but one instance.

Once a tag response was received, a personalized handwritten letter promptly acknowledged its receipt and told where and when the fish had been released. Of course, a check for the $1.00 reward was sent and, in many instances, a reprint of a fishery information leaflet was enclosed. A file containing each recapture was generated. It contains the correspondent's response. Our data process method was done without electronic data equipment. Several volumes of notebooks containing all information pertaining to all the tags were produced. Each day's releases by site of release are listed therein in sequence of tag number with each entry release data and recapture information. Each day's work was termed a sample and for each sample a summary chart for each species released was

kept up-to-date with the new information as it came in to us. These charts provided the information for the summary charts included here.

RESULTS

Table 1 lists the species tagged and released by year and summarizes the number of recaptures for each. Figures 1 to 26 indicate by numbers where each species was tagged and released. Most fish were obtained from commercially operated stake and drift gill nets. Some fish were collected by our own beach seines and by the otter trawl net from RV/ORION and RV/AQUARIUS. The fish were always released at the site where they were caught. Each fish was only out of water long enough to be measured and tagged, two minutes at most.

Figures 27 and 28 summarize the length frequency distributions of tagged (dotted bars) and recaptured (solid bars) fish for striped bass and white perch, respectively. Both sexes are combined in these figures.

Striped bass were tagged in all three years, 1971 to 1973. The largest number of fish were tagged and released at Turkey Point (Fig. 1, 17, and 26), with a much lesser number tagged in the Canal, in the tributaries, and in upper Chesapeake Bay. Turkey Point is the center of gillnet fishing in the Canal area.

White perch were tagged all over the Canal area and vicinity (Figs. 2 and 18), but the majority was from the two tributaries: upper Elk River and Bohemia River.

Most of the three species of catfishes were tagged and released at upper Elk River and Bohemia River (Figs. 4-6; 20-22).

Releases of all other species are more or less widely distributed over the Canal area.

1. Rate of Return

During the 3 years, 18 species totaling 9,004 fish were tagged and released at the capture sites. Percentage recaptures of each species by years varies from 0 to 50% (Table 1). Nine species, from blueback herring to spottail shiner, which were tagged only in 1971, had no recaptures at all. Three reasons may account for this lack of recaptures: the small numbers of fish tagged, the small size of tagged fish, and the absence of commercial fishery for the fish.

The nine species that yielded recaptures are all food fishes and subject to commercial gear, which is the main source of all recaptures. The recapture rates of from 8.2% for channel catfish to 27.3% for hickory shad are fairly good. The recapture rates of 2.0% for brown bullhead and 1.5% for white perch are low. A major reason for these low rates is that most of the fish tagged for these two species were too small to be recaptured by commercial gillnets.

Methods of Recapture

Recoveries of our released tags depended primarily upon commercial fishermen who recaptured tagged fish and returned the tags to us. Our own effort in recapturing tagged fish was minimal; it happened only during our regular trawling surveys.

Most of the fishermen who recaptured the tagged fish voluntarily returned the tags to us. But personal visits by our biologist produced additional number of tags which would otherwise be unreported.

Table 2 summarizes the methods of recapture. As can be seen, commercial gillnets alone account for 592 (95%) of the total 625 recaptures. In comparison, sport fishery reports only 14 (2%) recaptures.

Month of Recapture and Time at Large

1. Striped bass (Table 3). Since 95% of all recaptures were made by commercial gillnetters, it follows that most of the recaptures were made during the spring gillnetting season, i.e., March to May. Of the 492 recaptures, 478, or 97%, were made during this 3-month period.

Nearly every three of four recaptures (366 of 492) were made in the same month when the tagged fish were released. The longest time at large was 2 years, when a February 1971 release was not recaptured until February 1973. The complete breakdown of all recaptures by time at large is as follows:

Recaptured within the month of release	366	74%
" in the following month	98	20%
" 2 months after release	18	4%
" 3 " " "	1	.2%
" 6 " " "	1	.2%
" 7 " " "	1	.2%
" 8 " " "	1	.2%
" 11 " " "	2	.4%
" 1 year " "	3	.6%
" 2 years " "	1	.2%
	492	

2. White perch (Table 4). As in the case of striped bass, most of the recaptures (89 out of 96, or 93%) were made during the March-May period. The largest proportion of recaptures were made within a month or two. The longest time at large was 13 months.

Recaptured within the month of release	......	58	60%
" in the following month	....	29	30%
" 2 months after release	....	1	1%
" 3 " " "	....	1	1%
" 6 " " "	....	1	1%
" 11 " " "	....	2	2%
" 12 " " "	....	1	1%
" 13 " " "	....	3	3%

3. Channel catfish (Table 5). Total recaptures only amounted to 8, 6 of which were made during April and May. Half of the recaptures were relatively long term. One tagged fish each was at large for 3, 7, 8, and 9 months, respectively.

4. Brown bullhead (Table 6). Only 9 recaptures were made in total: 4 in March-April, and 5 in June-July. Only 3 tagged fish were recaptured within a month or two; one each after 5, 6, and 9 months; and 2 after one year at large.

5. Yellow perch (Table 7). Total recaptures were few (6), but fairly high in percentages (17%). All but one were recaptured in March-April. All were short-term recaptures - no tagged fish were at large beyond 2 months.

Length Distribution of Tagged and Recaptured Fish

Of the nine species of fish that were tagged and had some recaptures, only striped bass and white perch yielded any substantial number of recaptures: 492 for the former and 96 for the latter. We therefore selected these two species for a study of length frequency distributions of both tagged fish and recaptured fish.

1. Striped bass (Fig. 27). The dotted bars represent tagged fish; and solid bars, recaptured fish. All frequencies for tagged fish are in percentages; those for recaptured fish are in numbers. Relatively a higher percentage of larger fish were recaptured than when they were released. This is especially obvious in the May 1972 release. Another prominent point that stands out is that even though there was a large number of small fish tagged, no fish smaller than 165 mm (6 1/2 inches) was recaptured. Indeed, most of the fish recaptured were 305 mm (12 inches) or longer. This is because 12 inch F.L. is the minimum legal size allowed in Maryland, and all gillnet mesh sizes are geared to catch larger fish. The few smaller fish recaptured were due to entanglement in the webbing by the dangling Carlin tags, which were applied to fish smaller than 12 inches.

2. White perch (Fig. 28). Most of the recaptures were made by commercial gillnetters during the spring fishing season. This accounts for the relative absence of recaptures from June to October tagging in spite of large numbers of releases. The legal minimum size limit for white perch is 8 inches (203 mm), but a fairly good proportion of recaptured fish were smaller than 8 inches because of the Carlin tag. The complete lack of recaptures from the large releases of July 1971 (1,332 releases) and June 1972 (1,876 releases), and the small returns from September 1971 (953 releases) and October 1971 (842 releases) are difficult to understand. Perhaps longer term recaptures might be reported later.

Migration Routes and Recapture Sites

Figs. 30 a-y depict the generalized release locations and recapture sites for each species. The squares or rectangles indicate the location

and number of releases. The circles indicate the site and number of recaptures. The arrows indicate the probable migration routes.

1. Striped bass (Figs. 30 a-h). The generalized release locations can be grouped into three: (1) western entrance of the Canal (Figs. 30 c-e, h), (2) in the Canal (Figs. 30 a and g), and (3) upper Chesapeake Bay off Worton Point (Figs. 30 b and f). From all three release locations, tagged fish had migrated in two opposing directions: eastward toward Delaware Bay and westward into Chesapeake Bay. One fish went out of Delaware Bay and was recaptured off New York. This is the most direct and conclusive evidence that striped bass use the C and D Canal as a migration route in and out of Chesapeake Bay.

The number of recaptures depends heavily upon fishing effort. Therefore, unless and until weighting factors can be applied to these numbers for Chesapeake versus Delaware recaptures according to respective fishing intensities in both bays, it would be meaningless to calculate percentage recaptures from these areas. The significant point is that striped bass did migrate through the Canal in both directions.

2. White perch (Figs. 30 i-o). The same general inference can be drawn on the white perch as on the striped bass in regard to migration routes. Fish migrate in both directions toward Delaware and Chesapeake bays.

3. Yellow perch (Figs 30 p-r). Too few recaptures were made to yield conclusive evidence of migration pattern. But aside from the 3 that were recaptured in Elk River at the release site (Fig. 30r), the remaining three all migrated westward. Most probably these migrations were for the purpose of spawning.

4. Brown bullhead (Figs. 30 s,t). The three recaptures in Bohemia River were made in the vicinity of release site, indicating very little migration. However, the recaptures from Elk River releases indicate both upstream and downstream movements. There was no recapture that indicates an eastward migration through the Canal.

5. Channel catfish (Figs. 30 u, v). Recaptures indicate a downstream movement toward Turkey Point and an intertributary movement between Elk and Bohemia rivers. No recapture was made east of Welch Point, indicating a lack of eastward movement into the Canal.

6. Hickory shad (Fig. 30w). All 6 recaptures were made in the vicinity of release site. The small number of releases precludes conclusion regarding migration pattern. Hickory shad is an anadromous species, however, and it must move extensively.

7. Alewife (Fig. 30x). Again, only a small number of releases and recaptures are available. The 3 recaptures indicate two that migrated eastward toward the two tributaries and one that was caught right at release site.

8. American shad (Fig. 30y). Only 3 recaptures were made from 15 releases. Two were recaptured at release site, and one migrated down bay.

9. White catfish. There was only one recapture at Welch Point. This came from a release of two tagged fish at Turkey Point.

Summary and Discussion

Tagging and recapture studies of various species of fish have provided direct evidence that fish either migrate back and forth through the C and D Canal or move from place to place within the Canal. The striped bass and white perch were found to migrate in both directions. Other anadromous

species such as the alewife, American shad, and hickory shad are known to migrate through the Canal and into the upper Chesapeake Bay or out into the ocean even though our own tagging and recapture studies failed to reveal the entire migration pattern due to limited number of fish handled.

The tagging work performed by scientists at the College of Marine Studies of the University of Delaware (Ronal W. Smith, et al. Appendix IX. Fish Movement-Delaware Study) does show that all these three species migrate from Delaware River to Chesapeake Bay.

The yellow perch, channel catfish, and white catfish are freshwater species. While our tagging results indicate only a limited extent of movement within the Canal or into the Chesapeake Bay, Delaware's tagging indicates that they too migrate through the length of the Canal from Reedy Island into upper Chesapeake Bay.

The brown bullhead is another freshwater species whose movement appears to be confined within a limited area in the Canal system. No definite conclusion can be drawn, however, since no brown bullhead was tagged on the Delaware side.

The tagging work proves that the C and D Canal provides a migration route for many important food fishes. For anadromous species, the Canal means a short cut from the ocean to their spawning grounds in upper Chesapeake Bay and from the Bay back to the ocean after spawning. The free movement of other resident species of fishes between Delaware and Chesapeake bays would tend to enhance species diversity in both areas. It is inconceivable that enlargement of the Canal would have detrimental effects on fish migration. Any locking device, if installed, however, could alter the migration patterns and deter the free movement of fishes through the Canal.

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Nichols, P. R., and R. V. Miller. 1967. Seasonal movements of striped bass, Roccus saxatilis (Walbaum), tagged and released in the Potomac River, Maryland, 1959-61. Chesapeake Sci. 8(2):102-24.

Whitney, R. R. 1961. The Susquehanna Fishery Study, 1957-1960. Maryland Dept. of Res. & Ed., Solomons, Md., Contr. 169-1-81.

Table 1. Summary of all fish tagging and recapture by species. Recapture data through 14 June 1973.

Species	1971 Re-leases	1971 Recap-tures	1971 % Re-captures	1972 & 1973 Re-leases	1972 & 1973 Recap-tures	1972 & 1973 % Re-captures	Total Re-leases	Total Recap-tures	Total % Re-captures
Striped bass	168	20	11.9	1,751	472	26.9	1,919	492	25.6
White perch	4,323	86	2.0	1,989	10	0.5	6,312	96	1.5
American shad	0	0	-	16	3	18.8	16	3	18.8
Brown bullhead	397	6	1.5	62	3	4.8	459	9	2.0
Channel catfish	76	7	9.2	22	1	4.5	98	8	8.2
Yellow perch	20	2	10.0	15	4	26.7	35	6	17.1
Alewife	6	0	-	12	3	25.0	18	3	16.7
Hickory shad	0	0	-	22	6	27.3	22	6	27.3
White catfish	7	0	-	2	1	50.0	9	1	11.1
Blueback herring	3	0	0	0	0	-	3	0	0
Gizzard shad	15	0	0	0	0	-	15	0	0
Mummichog	21	0	0	0	0	-	21	0	0
Golden shiner	1	0	0	0	0	-	1	0	0
Striped killifish	2	0	0	0	0	-	2	0	0
Pumpkinseed	22	0	0	0	0	-	22	0	0
Bluefish	3	0	0	0	0	-	3	0	0
Spot	39	0	0	0	0	-	39	0	0
Spottail shiner	10	0	0	0	0	-	10	0	0
Totals	5,113			3,891			9,004		

Table 2. C & D Canal fish tagging studies. Recapture methods; data through 14 June 1973.

Species	Recaptured by						Total recaptures
	Commercial gill nets	Sports gear (hook & line)	Found dead	Our own trawl	Catfish pot	Unknown	
			From 1971 tagging				
Striped bass	16	2	1	0	0	1	20
White perch	75	4	3	3	0	1	86
Yellow perch	1	1	0	0	0	0	2
Channel catfish	4	1	0	0	2	0	7
Brown bullhead	2	3	1	0	0	0	6
			From 1972 tagging				
Striped bass	460	1	1		2		464
White perch	9	1	0		0		10
Yellow perch	3	1	0		0		4
Channel catfish	1	0	0		0		1
White catfish	1	0	0		0		1
Brown bullhead	0	0	3		0		3
Alewife	3	0	0		0		3
Hickory shad	6	0	0		0		6
American shad	3	0	1		0		4
			From 1973 tagging				
Striped bass	8	0	0		0		8
Totals	592	14	10	3	4	2	625

Table 3. Summary of striped bass tagging and recapture. Recapture data through 14 June 1973.

Month of release	Number released	Month of recapture	Number recaptured	Total recaptured	% recapture
Feb. 71	29	Feb. 71	1	-	-
		Apr. 71	3	-	-
		Feb. 73	1	5	17.2
Mar. 71	1	-	-	0	0
Apr. 71	54	Apr. 71	6	0	0
		May 71	6	-	-
		June 71	1	-	-
		Dec. 71	1	-	-
		Apr. 72	1	15	25.9
July 71	45	-	-	0	0
Sept. 71	7	-	-	0	0
Oct. 71	32	Oct. 72	1	1	3.1
Mar. 72	738	Mar. 72	192	-	-
		Apr. 72	73	-	-
		May 72	14	-	-
		Feb. 73	2	281	38.2
Apr. 72	599	Apr. 72	138	-	-
		May 72	18	-	-
		Oct. 72	1	-	-
		Apr. 73	1	158	26.4
May 72	305	May 72	21	-	-
		June 72	1	-	-
		Aug. 72	1	-	-
		Dec. 72	1	24	7.9
June 72	5	-	-	0	0
July 72	1	-	-	0	0
Apr. 73	103	Apr. 73	8	8	7.8
Totals	1,919	-	-	492	25.6

Table 4. Summary of white perch tagging and recapture. Recapture data through 14 June 1973.

Month of release	Number released	Month of recapture	Number recaptured	Total recaptured	% recapture
Feb. 71	389	Feb. 71	2	-	-
		Mar. 71	2	4	1.0
Mar. 71	351	Mar. 71	6	-	-
		Apr. 71	18	-	-
		Apr. 72	3	27	7.6
Apr. 71	399	Apr. 71	41	-	-
		May 71	5	-	-
		June 71	1	-	-
		Mar. 72	2	-	-
		Apr. 72	1	50	12.5
July 71	1,332	-	0	0	0
Aug. 71	57	-	0	0	0
Sept. 71	953	Sept. 71	1	1	0.1
Oct. 71	842	Oct. 71	2	-	-
		Jan. 72	1	-	-
		Apr. 72	1	4	0.5
Mar. 72	103	Mar. 72	5	-	-
		Apr. 72	3	8	7.8
Apr. 72	7	Apr. 72	1	-	-
		May 72	1	2	28.6
May 72	3	-	0	0	0
June 72	1,876	-	0	0	0
Totals	6,312	-	-	96	1.5

Table 5. Summary of channel catfish tagging and recapture. Recapture data through 14 June 1973.

Month of release	Number released	Month of recapture	Number recaptured	Total recaptured	% recapture
Feb. 71	1	-	-	-	0
Mar. 71	39	Apr. 71	4	4	10.2
July 71	21	-	-	0	0
Sept. 71	7	May 72	1	1	14.3
Oct. 71	8	May 72	1	-	-
		July 72	1	2	25.0
June 72	22	Sept. 72	1	1	4.5
Totals	98	-	-	8	8.2

Table 6. Summary of brown bullhead tagging and recapture. Recapture data through 14 June 1973

Month of release	Number released	Month of recapture	Number recaptured	Total recaptured	% recapture
Mar. 71	1	-	-	0	0
July 71	269	Apr. 72	1	-	-
		July 72	2	3	1.1
Sept. 71	41	-	-	0	0
Oct. 71	86	Mar. 72	1	-	-
		Apr. 72	2	3	3.5
Mar. 72	1	-	-	0	0
June 72	61	June 72	2	-	-
		July 72	1	3	4.9
Totals	459	-	-	9	2.0

Table 7. Summary of yellow perch tagging and recapture. Recapture data through 14 June 1973.

Month of release	Number released	Month of recapture	Number recaptured	Total recaptured	% recapture
Feb. 71	14	Apr. 71	1	1	7.1
Apr. 71	2	-	-	0	0
July 71	1	July 71	1	1	100.0
Sept. 71	1	-	-	0	0
Oct. 71	2	-	-	0	0
Mar. 72	10	Mar. 72	3	-	-
		Apr. 72	1	4	40.0
June 72	5	-	-	0	0
Totals	35	-	-	6	17.1

Figure 1 . Map of release sites of tagged striped bass, N= 168, 1971.

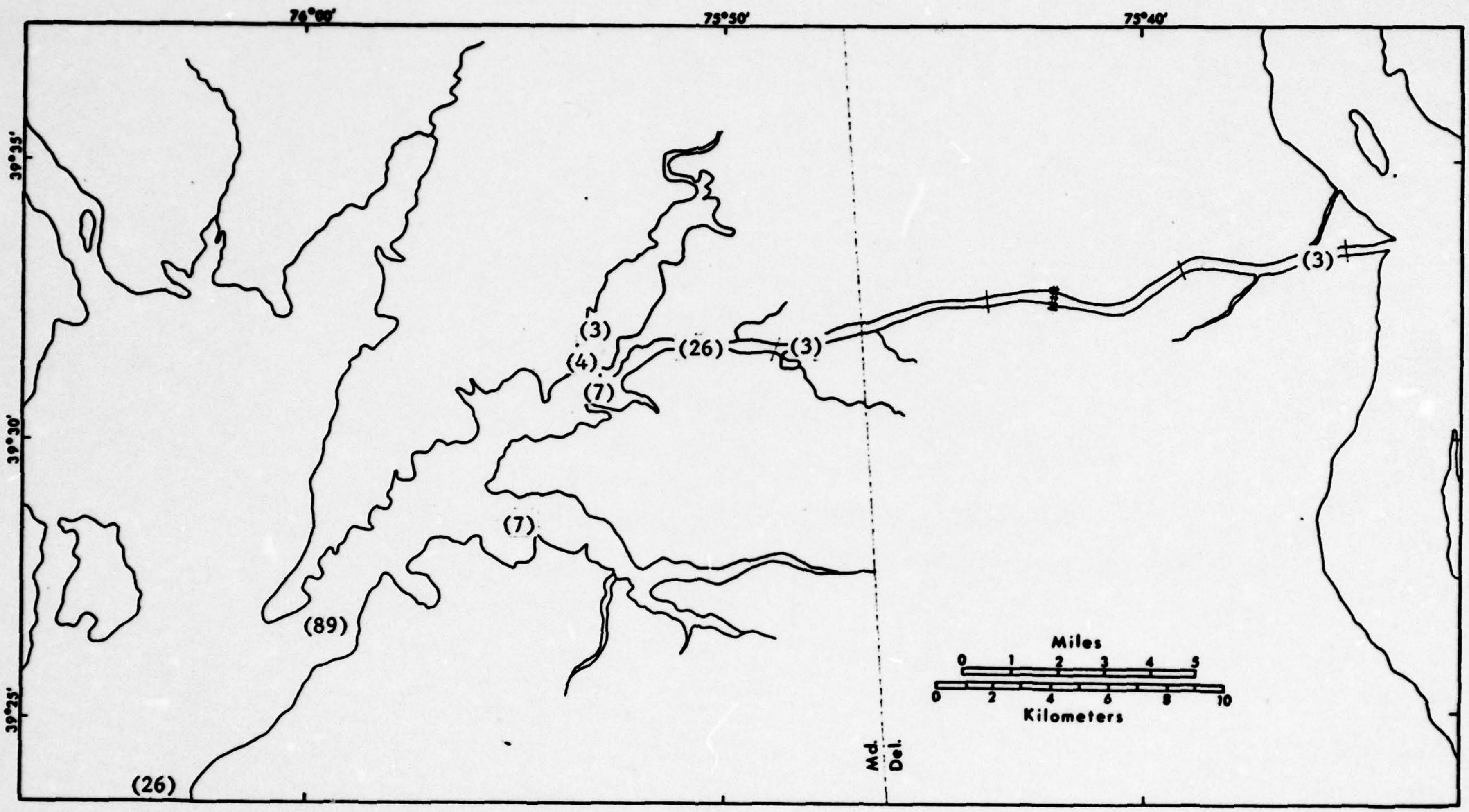


Figure 2. Map of release sites of tagged white perch, N= 4,323, 1971.

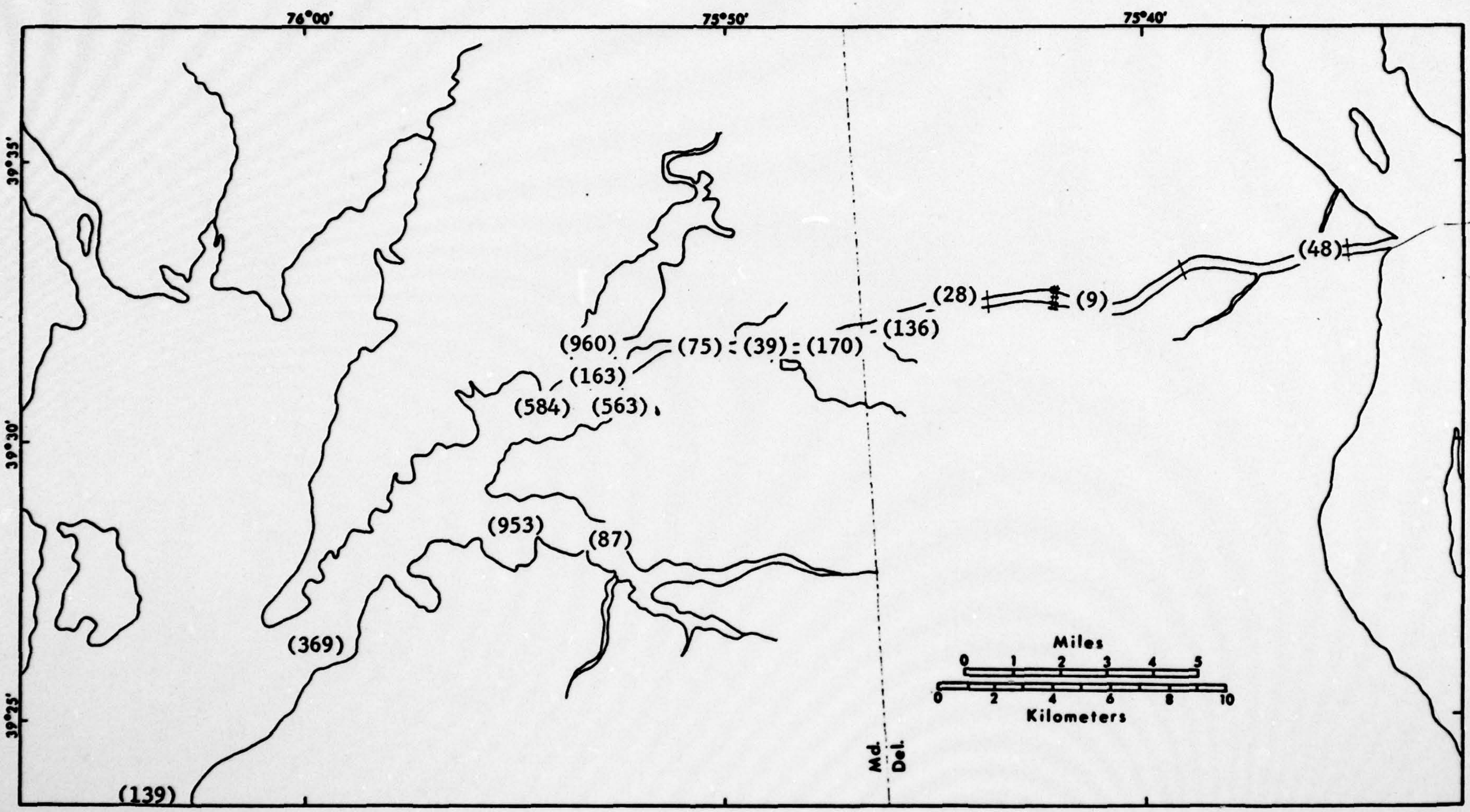


Figure 3. Map of release sites of tagged yellow perch, N= 20, 1971.

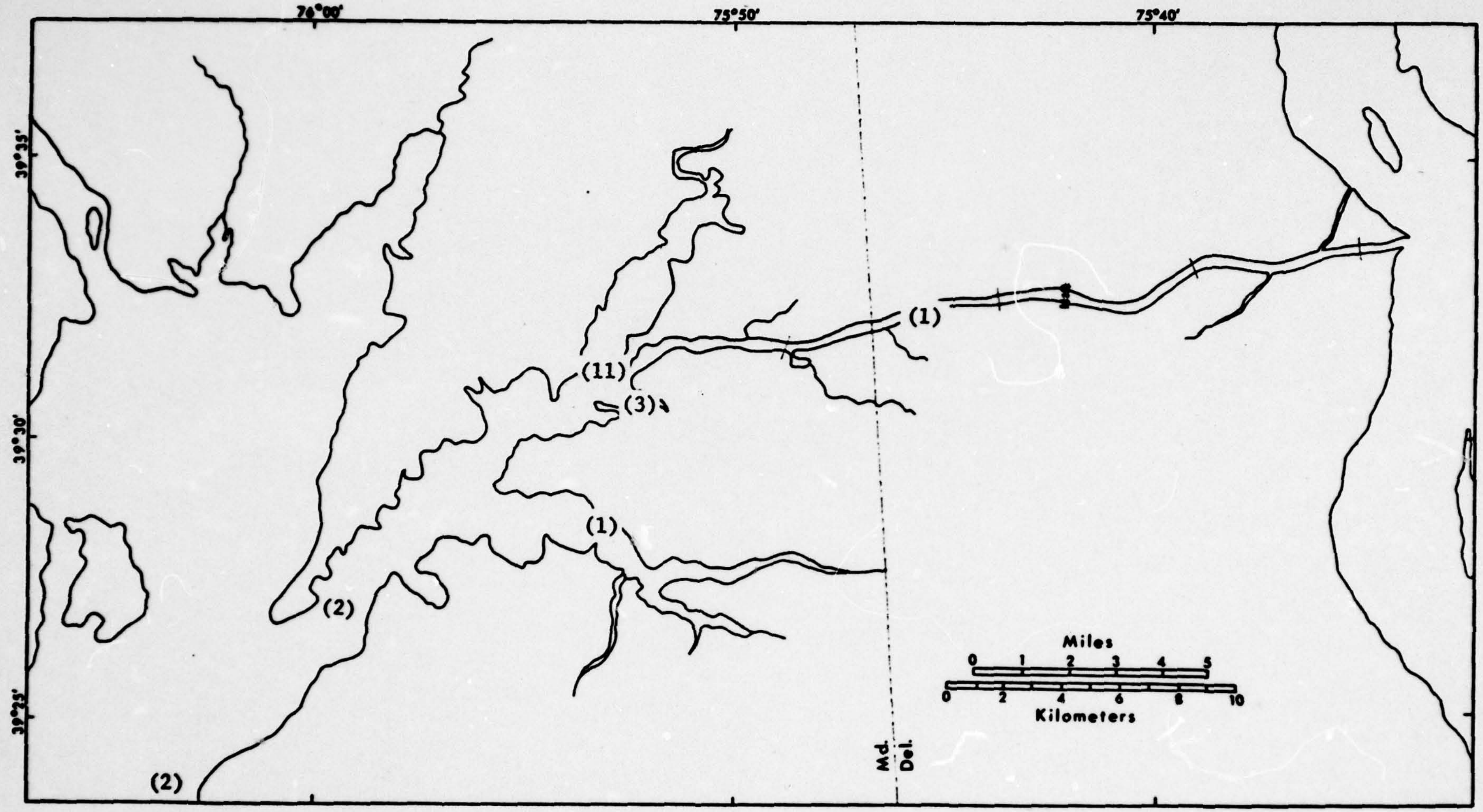


Figure 4. Map of release sites of tagged channel catfish, N=76, 1971.

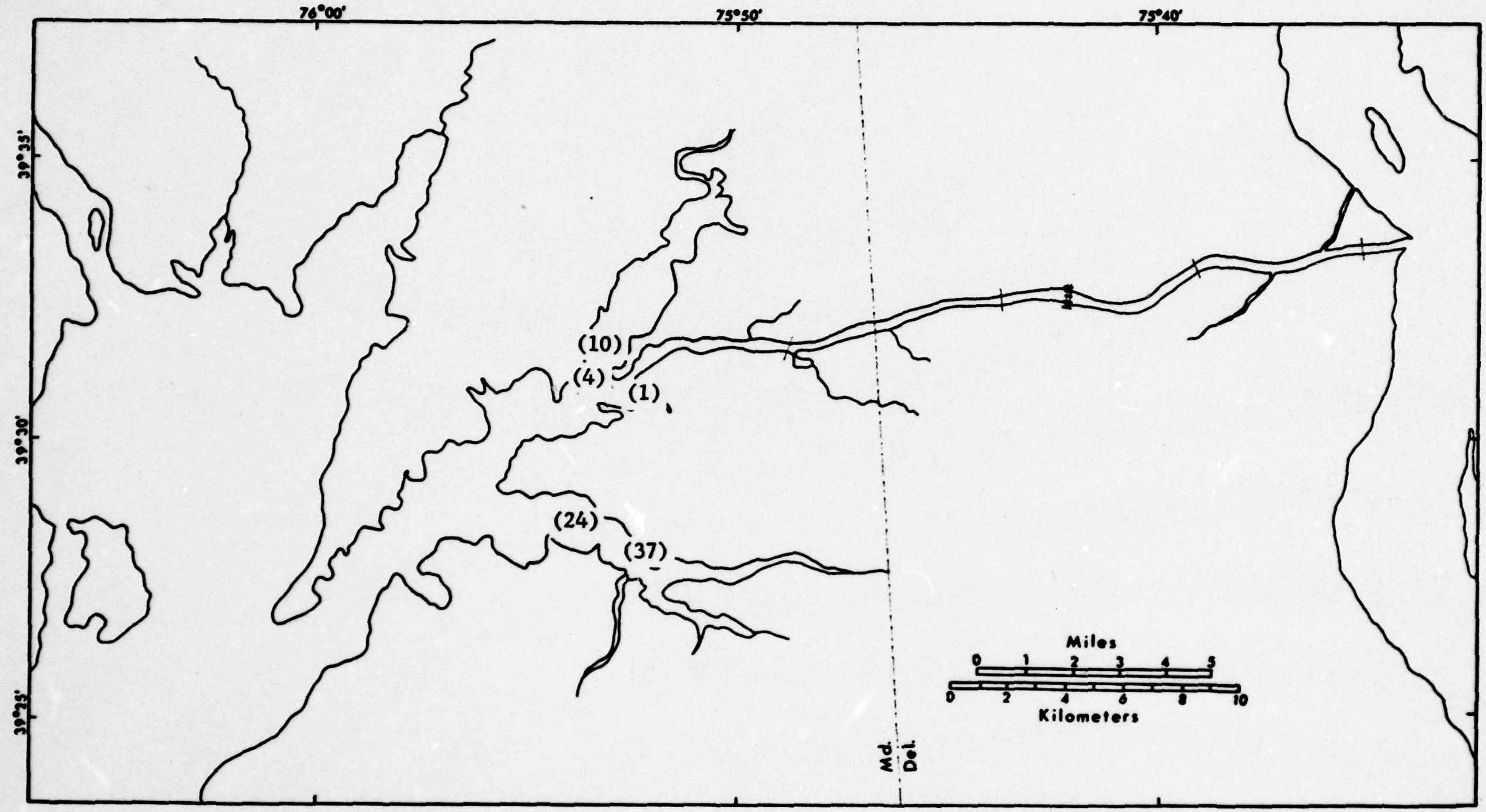


Figure 5. Map of release sites of tagged white catfish N= 7, 1971.

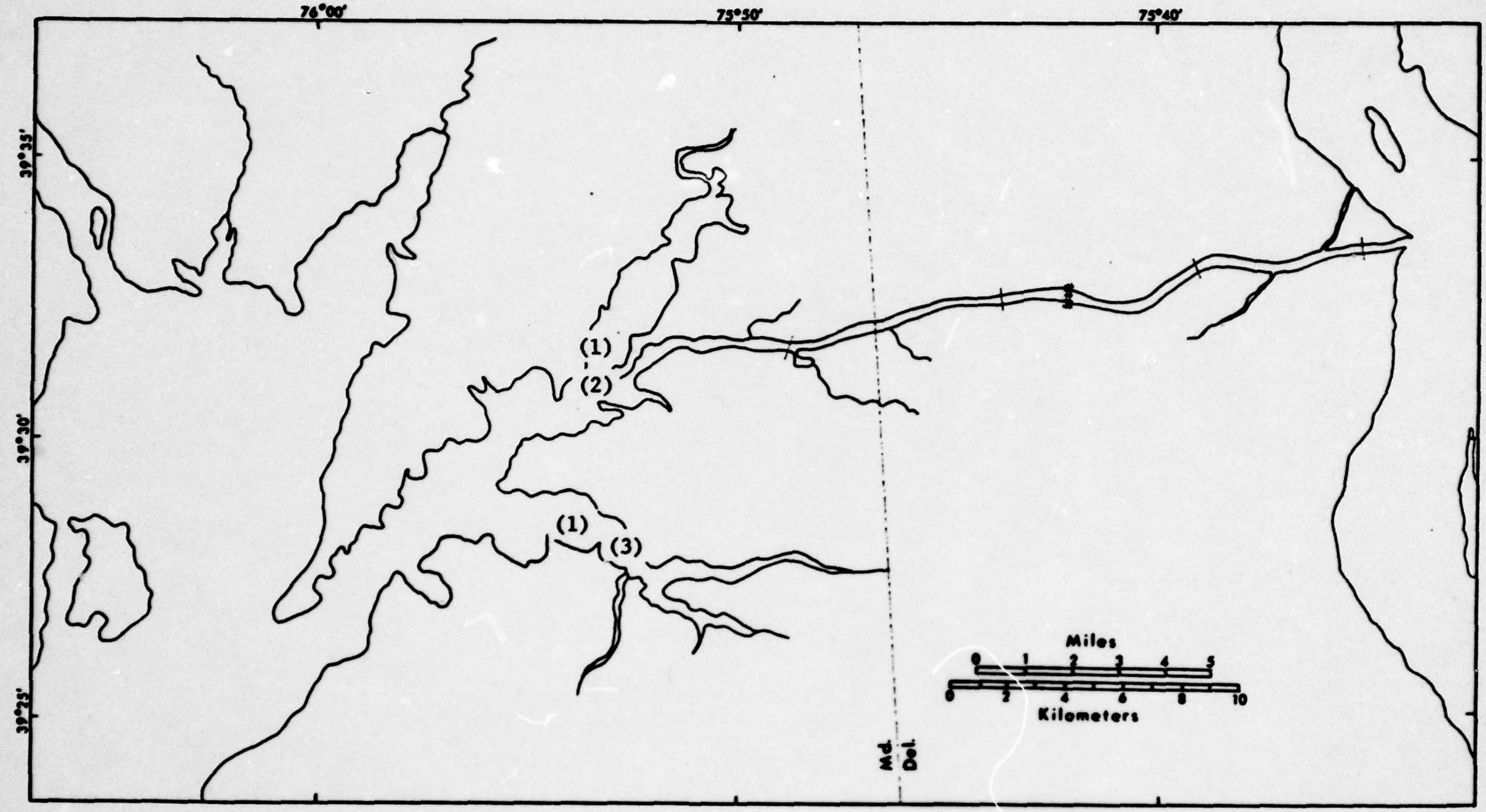


Figure 6. Map of release sites of tagged brown bullhead, N= 397, 1971.

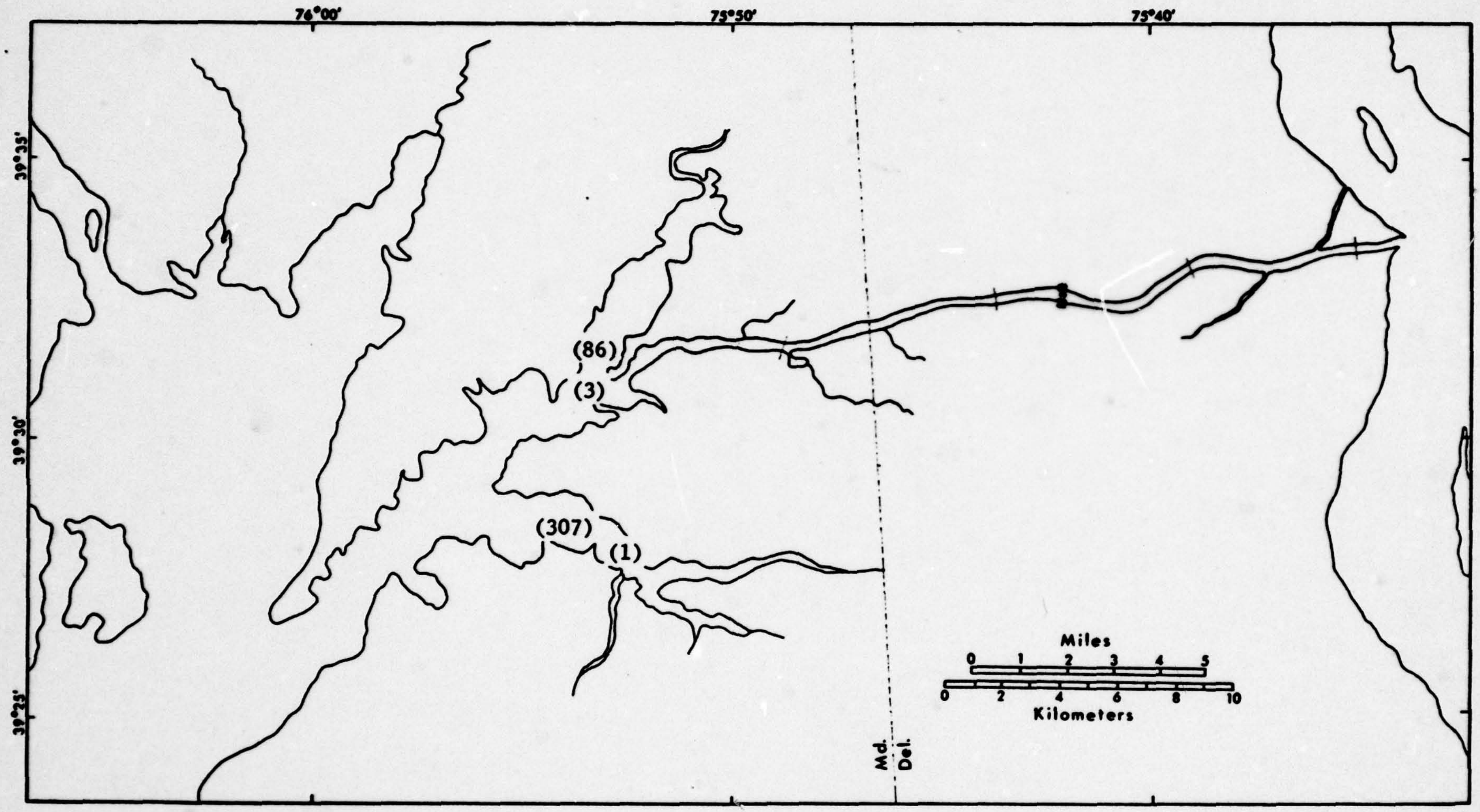


Figure 7. Map of release sites of tagged alewife N= 6, 1971.

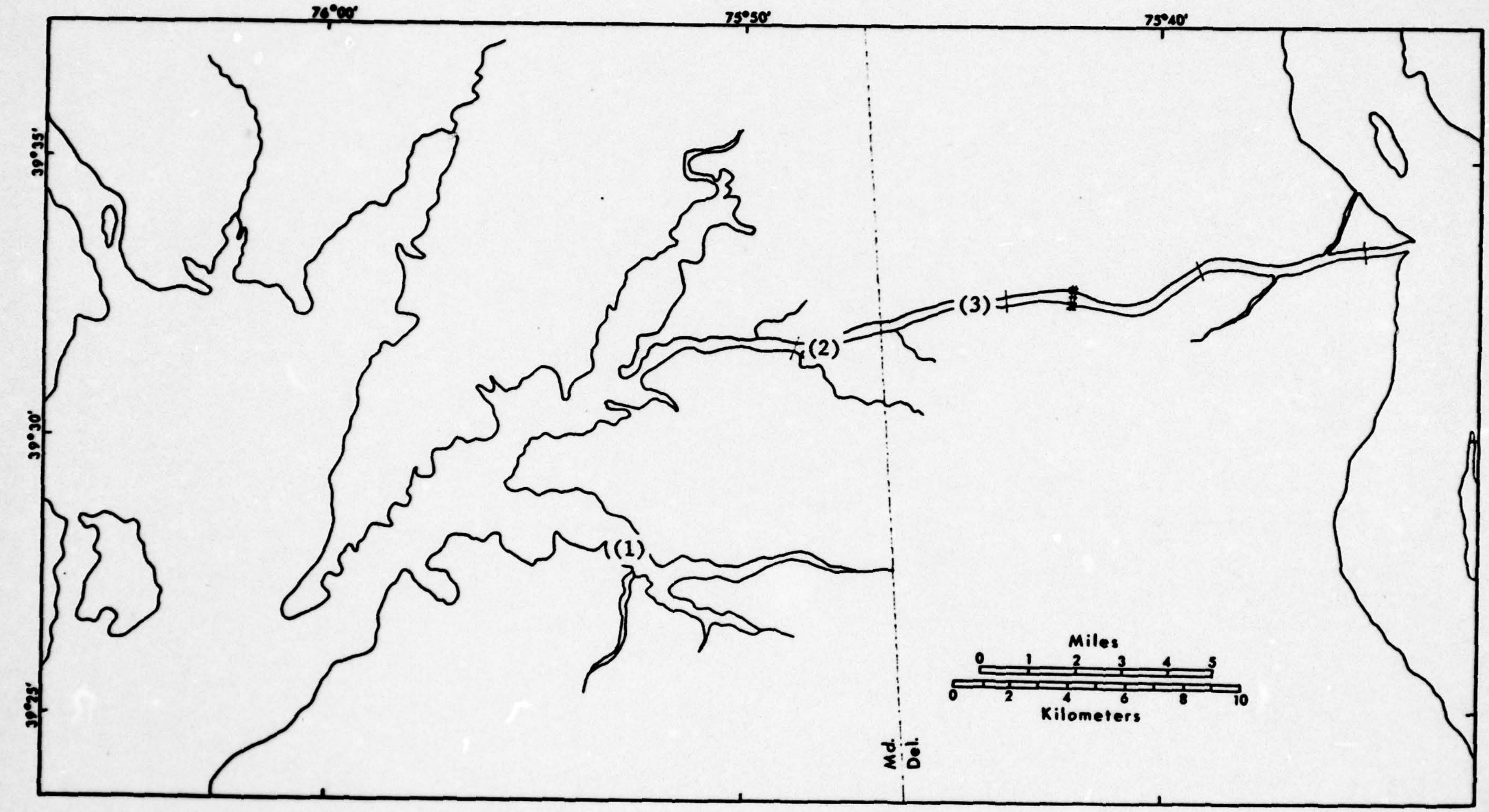


Figure 8. Map of release sites of tagged blueback herring, N=3, 1971.

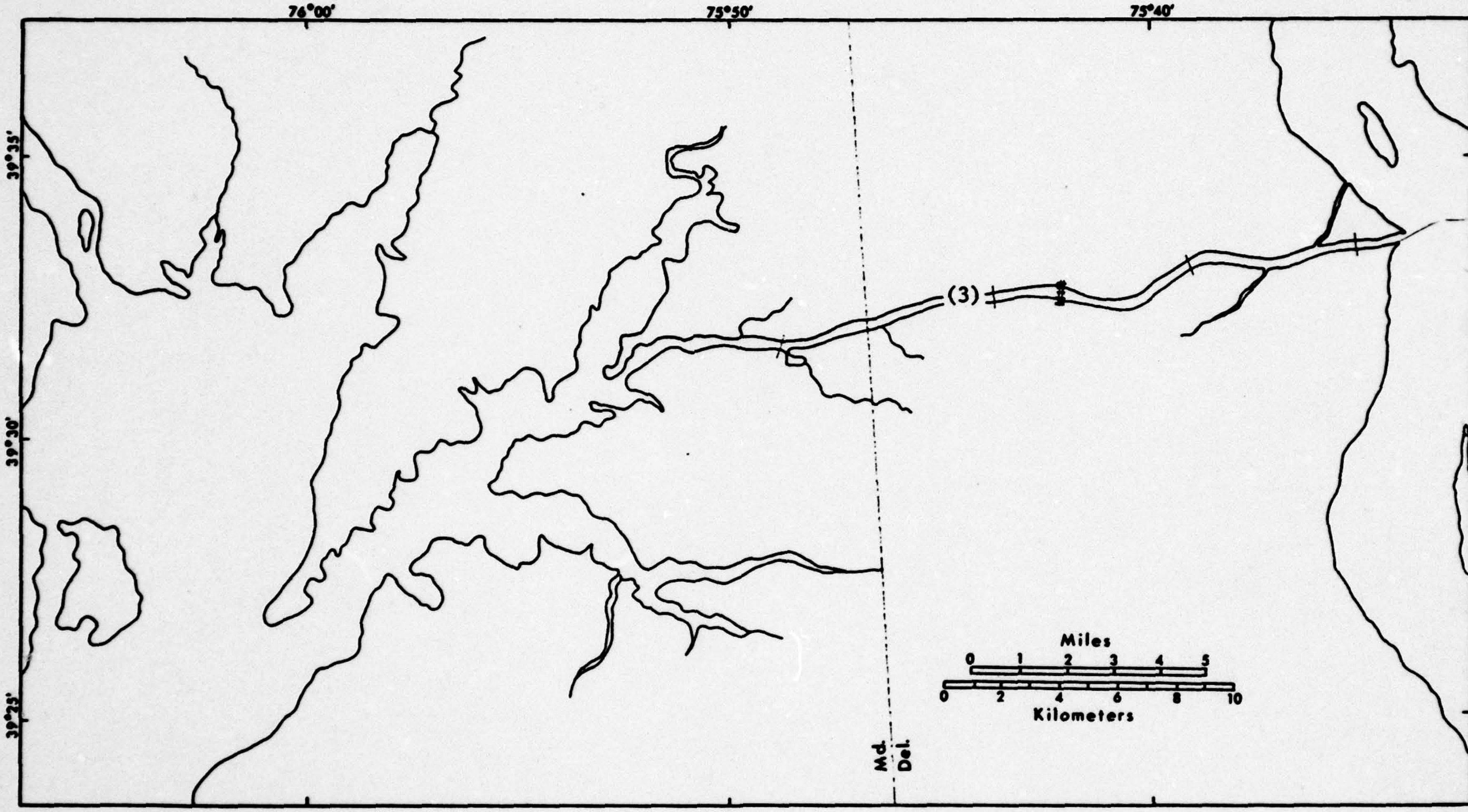


Figure 9. Map of release sites of tagged pumpkinseed, N= 22, 1971.

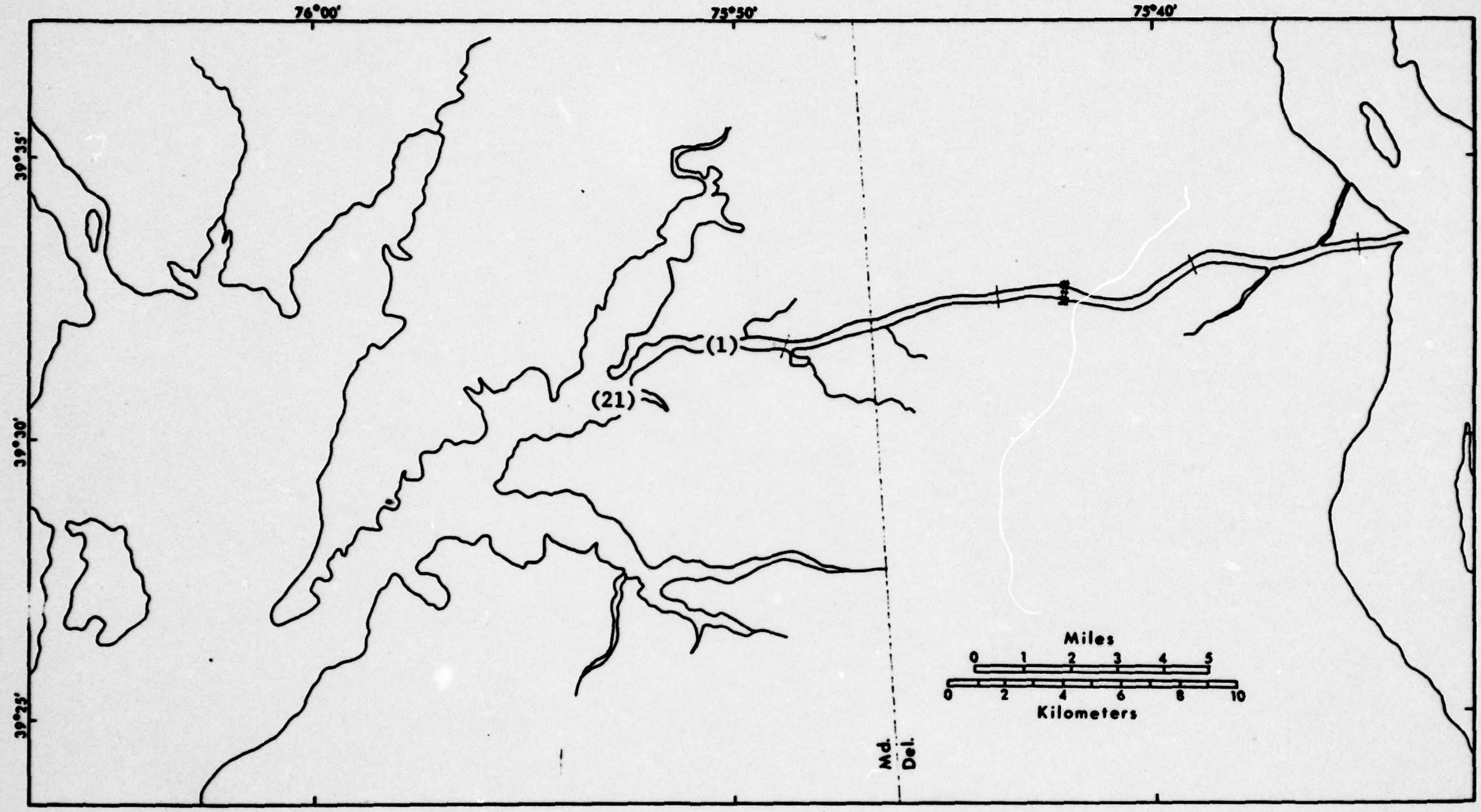


Figure 10. Map of release sites of tagged bluefish, N= 3, 1971.

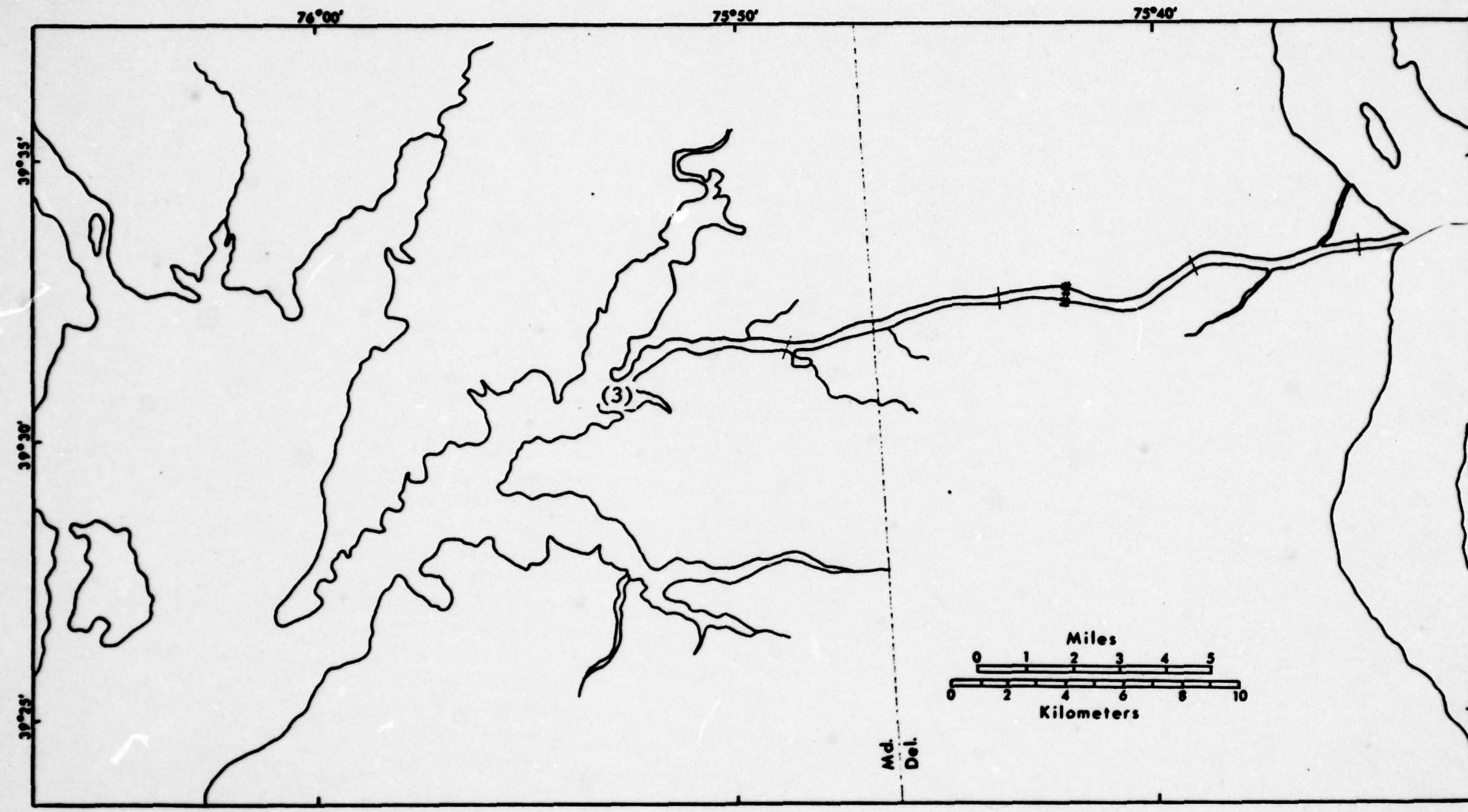


Figure 11.   Map of release sites of tagged mummichog, N= 21, 1971.

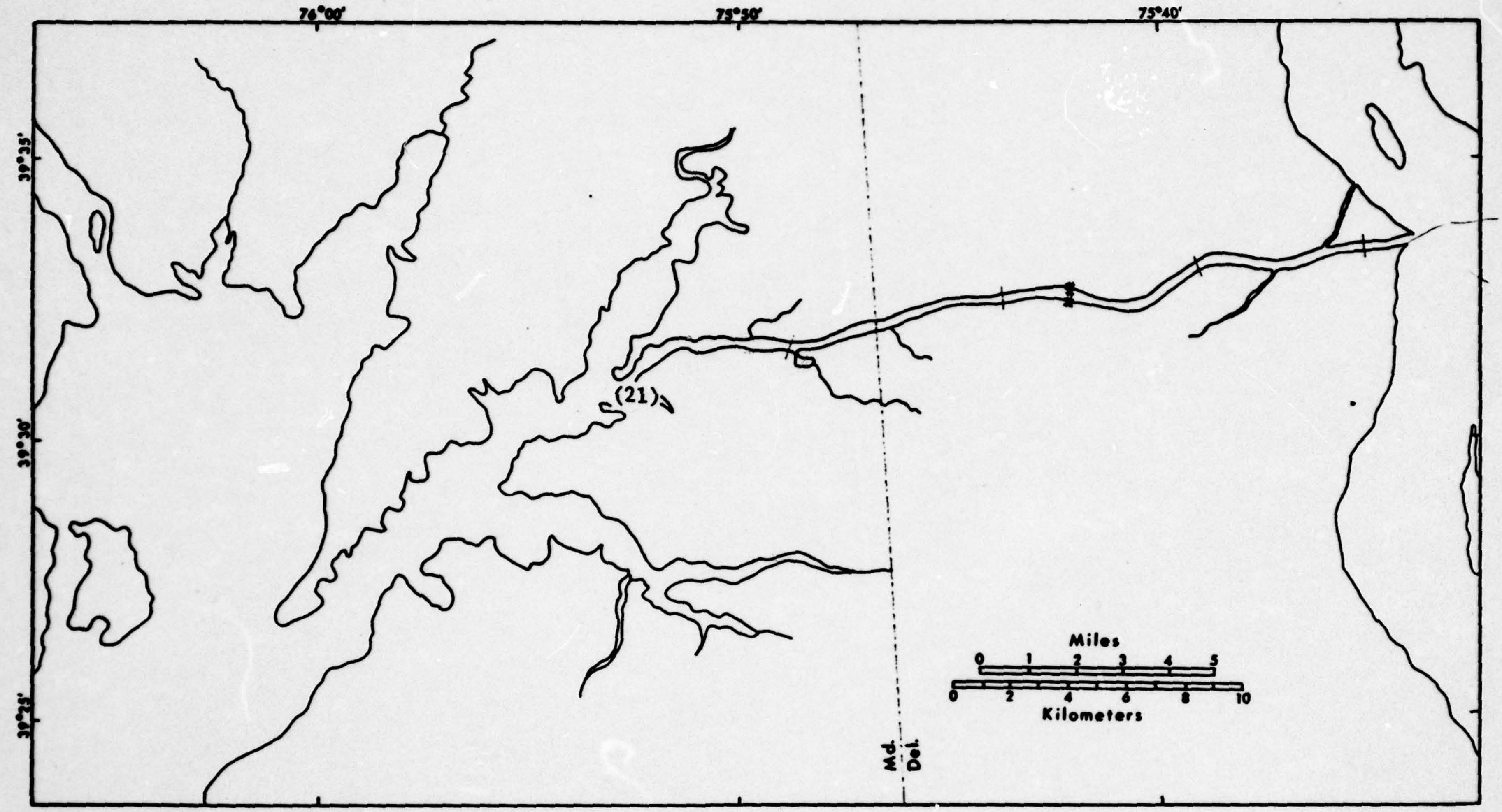


Figure 12. Map of release sites of tagged gizzard shad, N=15, 1971.

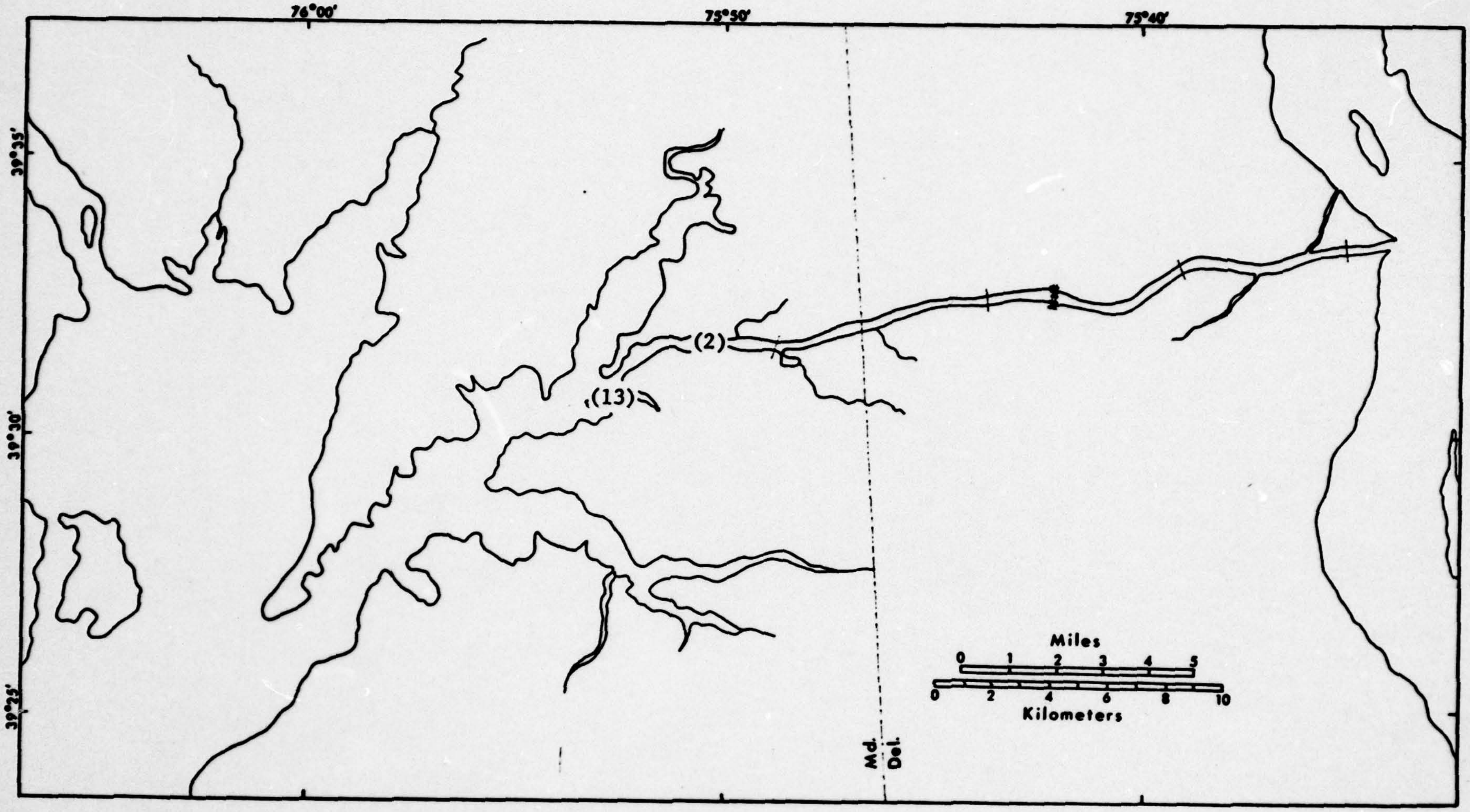


Figure 13. Map of release sites of tagged striped killifish, N=2, 1971.

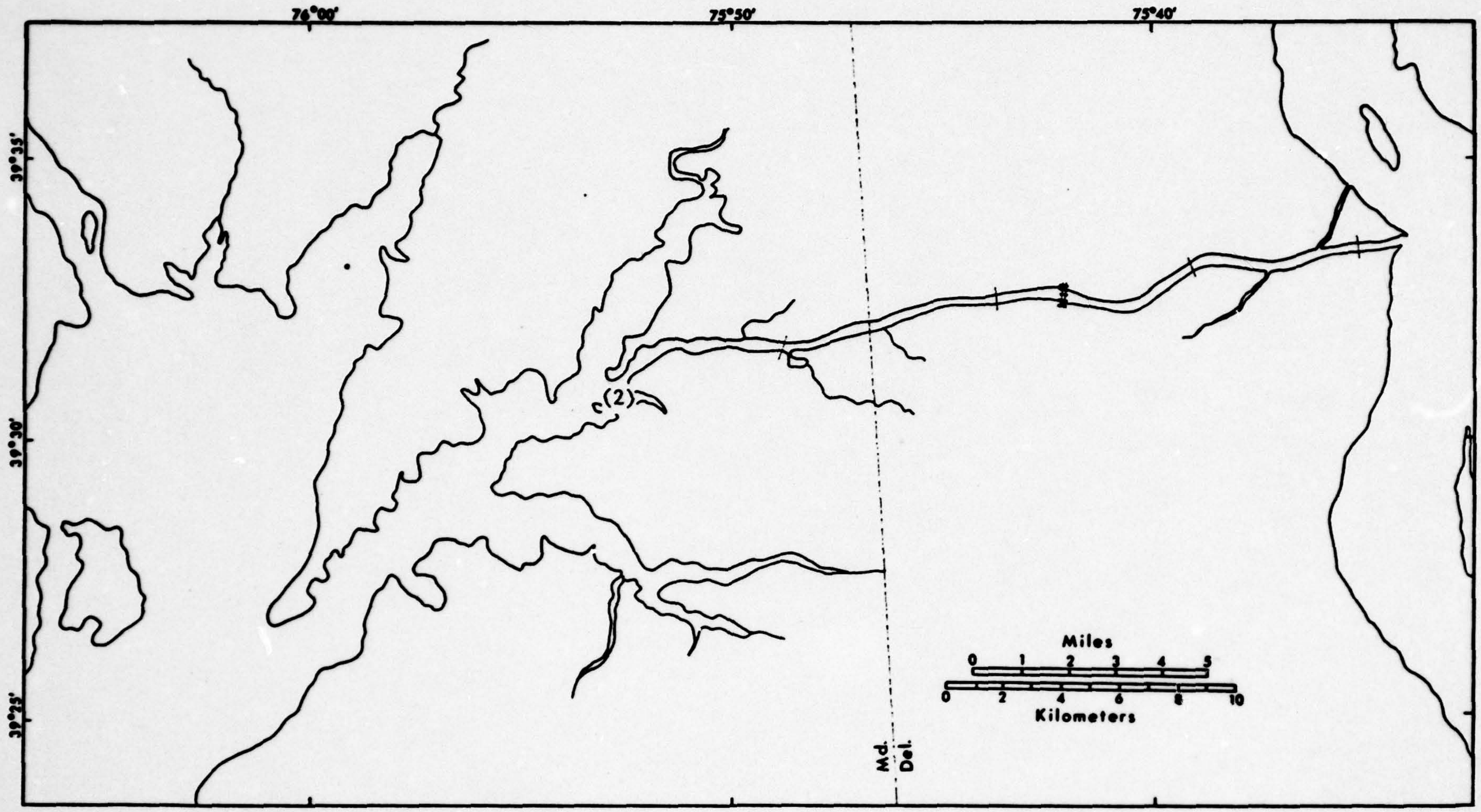


Figure 14. Map of release sites of tagged spottail shiner, N=10, 1971.

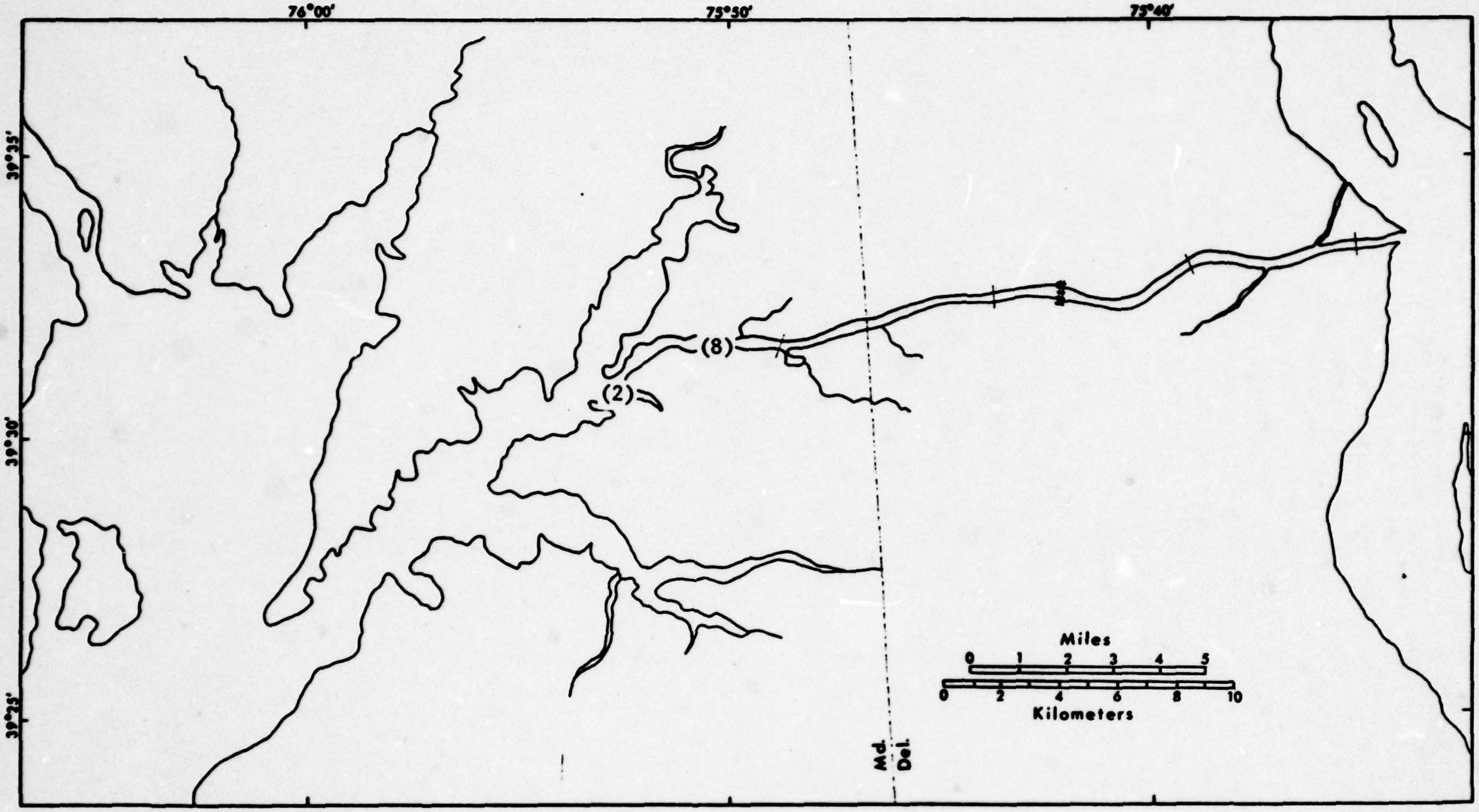


Figure 15. Map of release sites of tagged spot, N= 39, 1971.

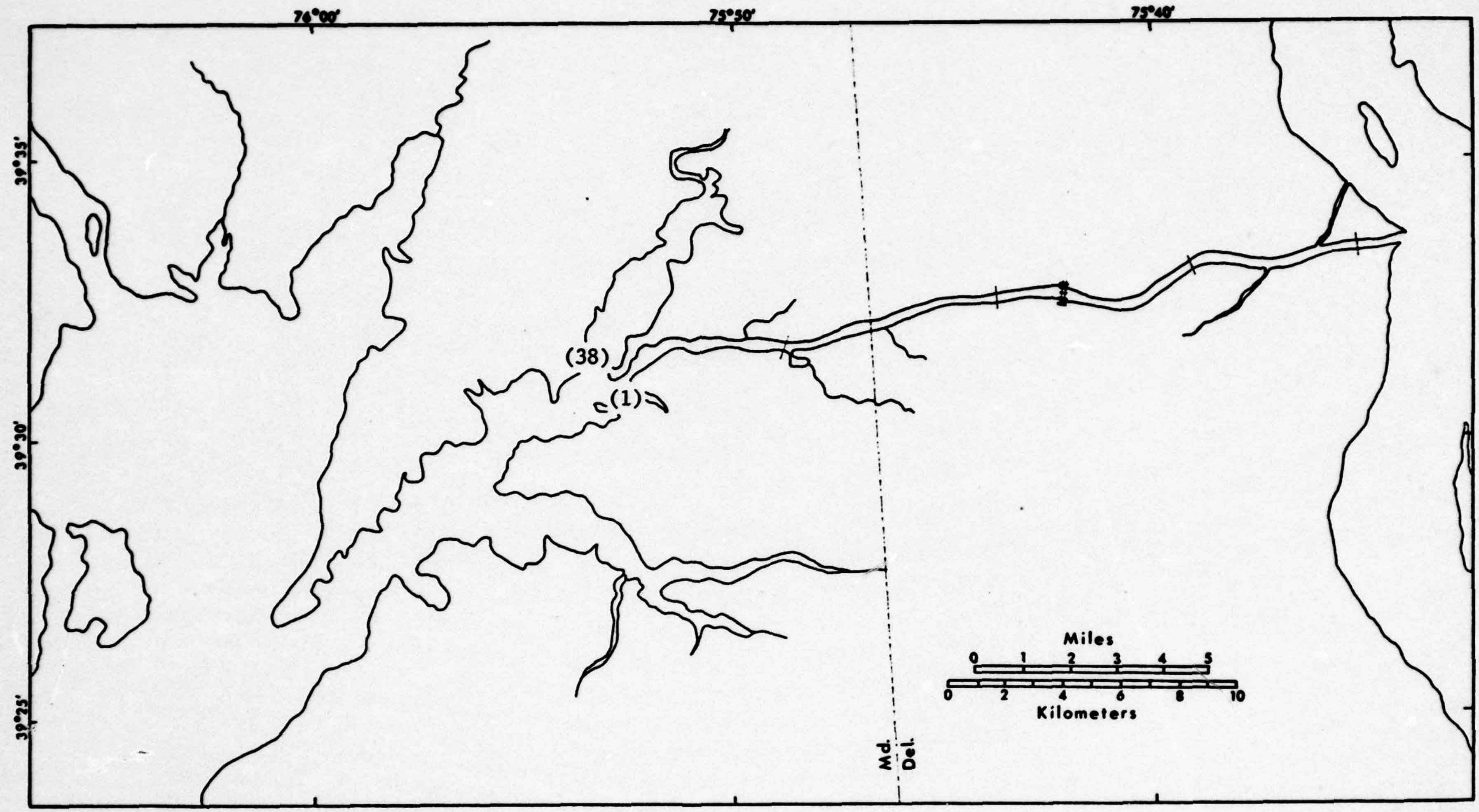


Figure 16. Map of release sites of tagged golden shiner, N=1, 1971.

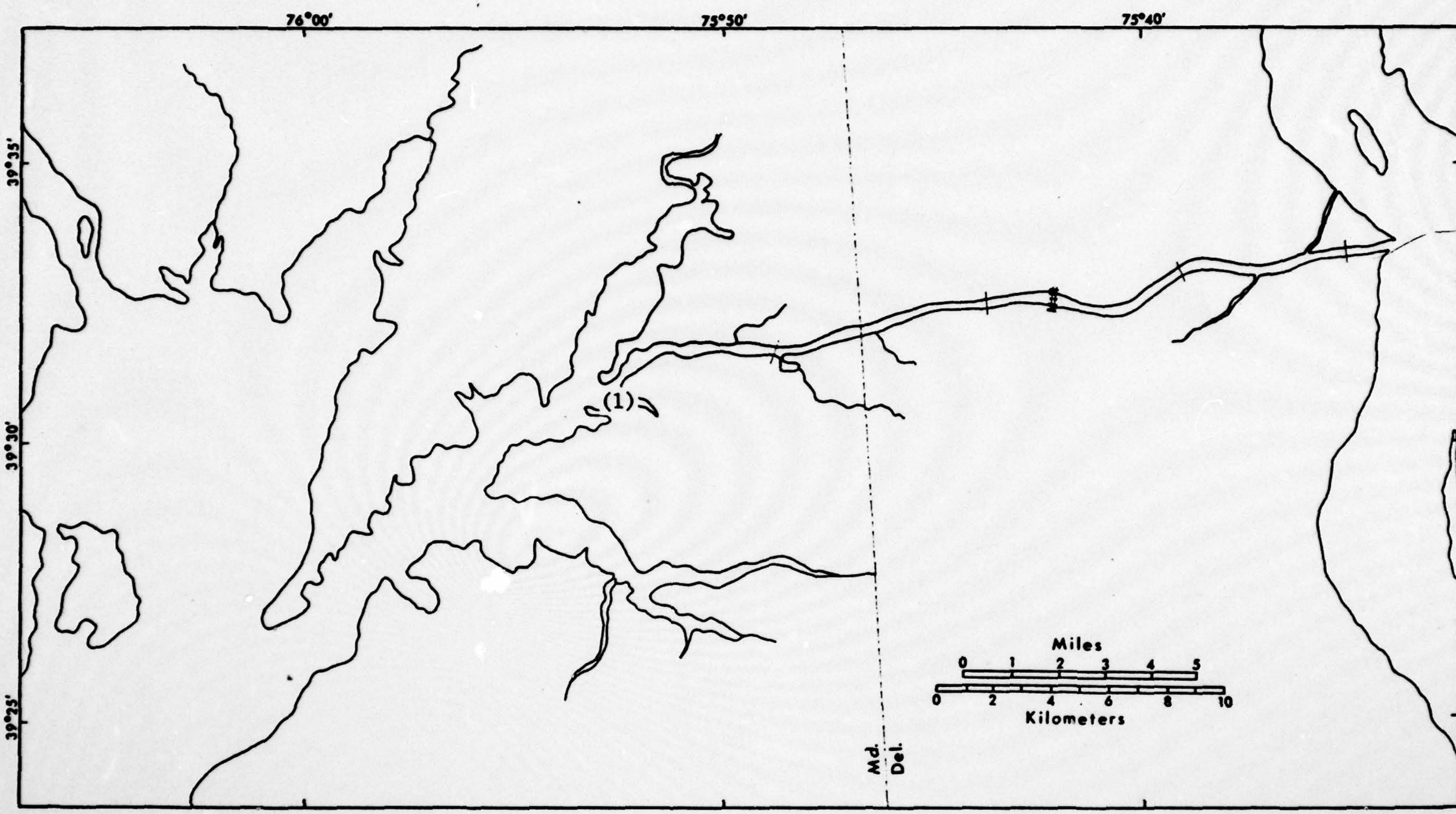


Figure 17. Map of release sites of tagged striped bass, N=1,648, 1972.

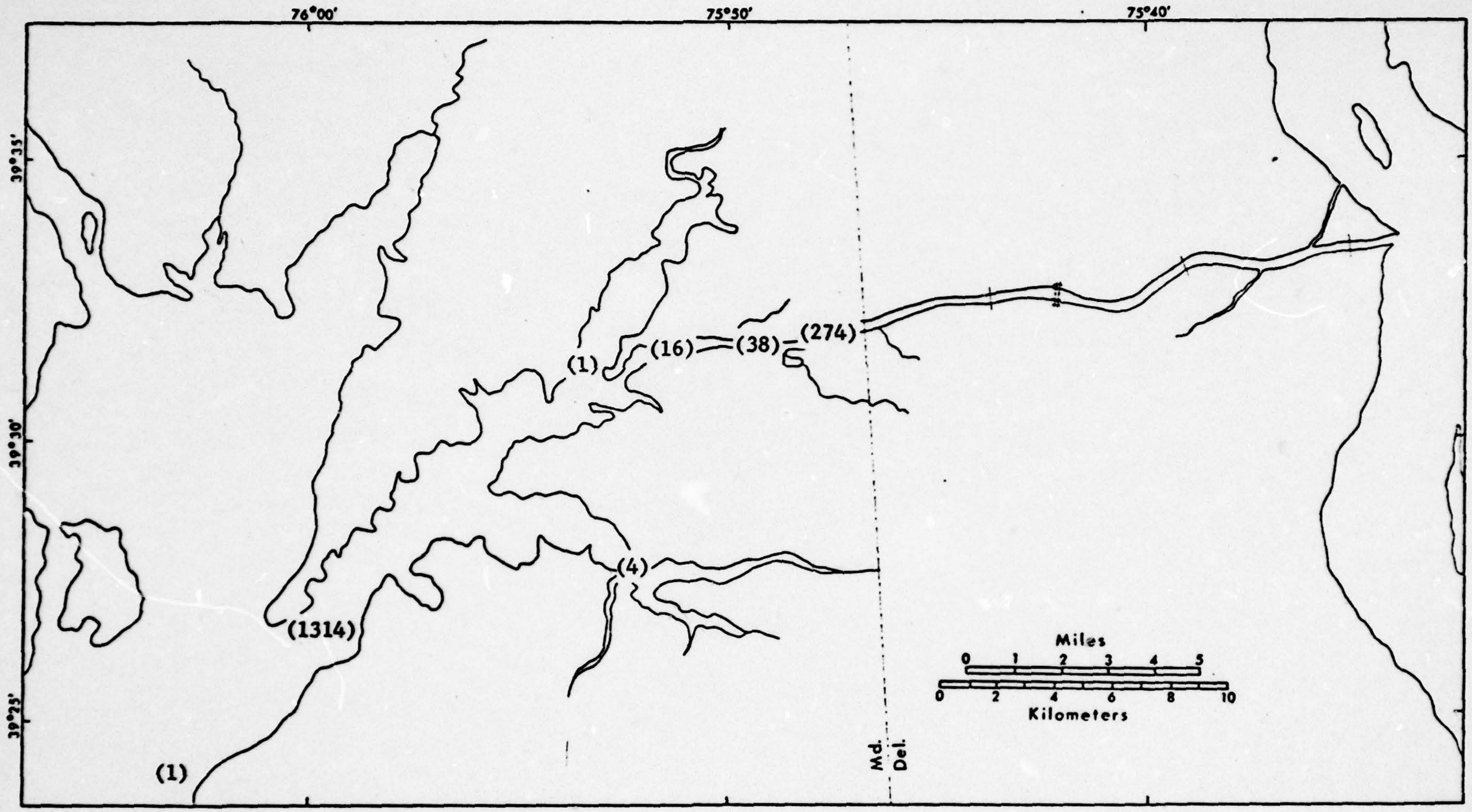


Figure 18. . Map of release sites of tagged white perch, N=1,989, 1972.

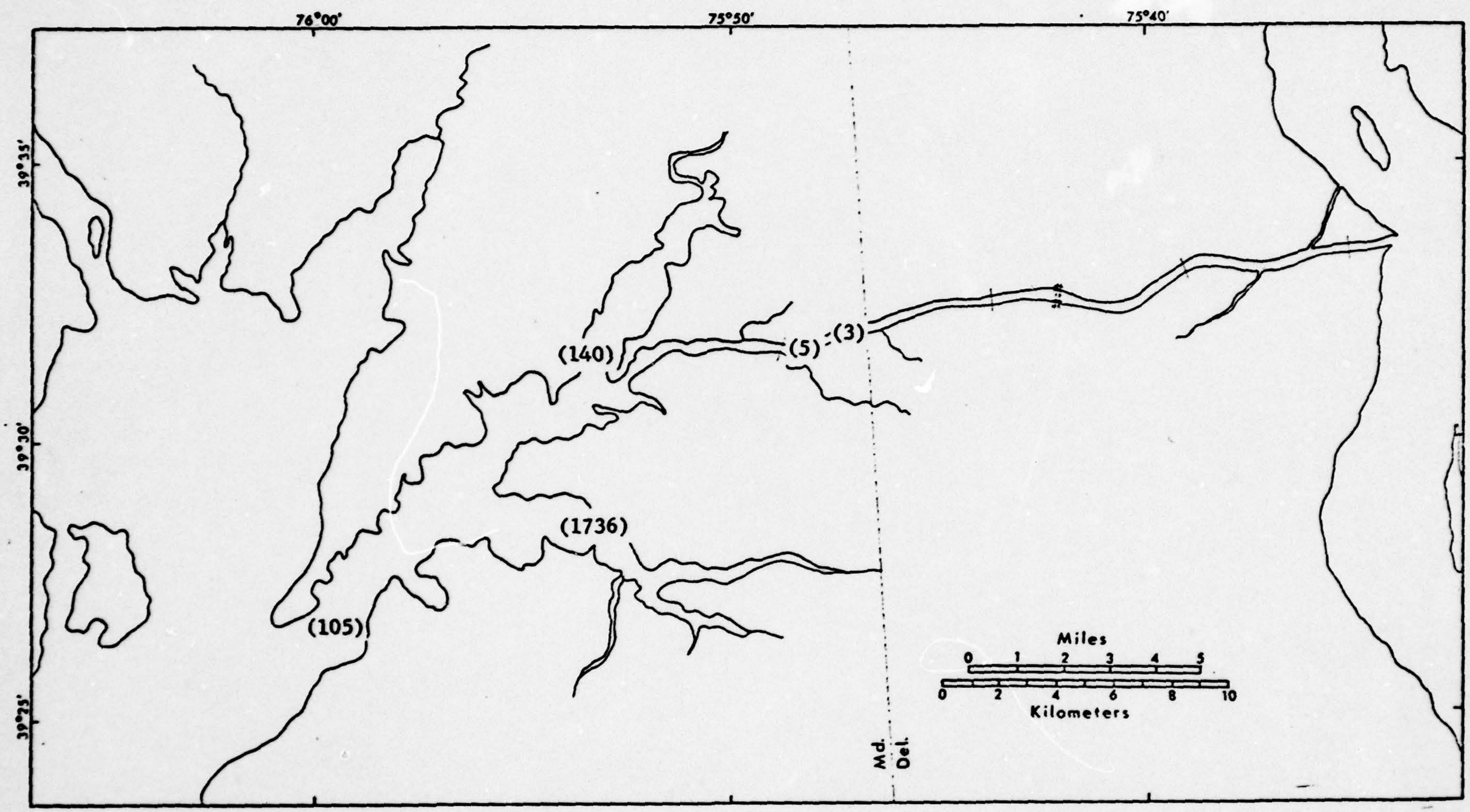


Figure 19. Map of release sites of tagged yellow perch, N= 15, 1972.

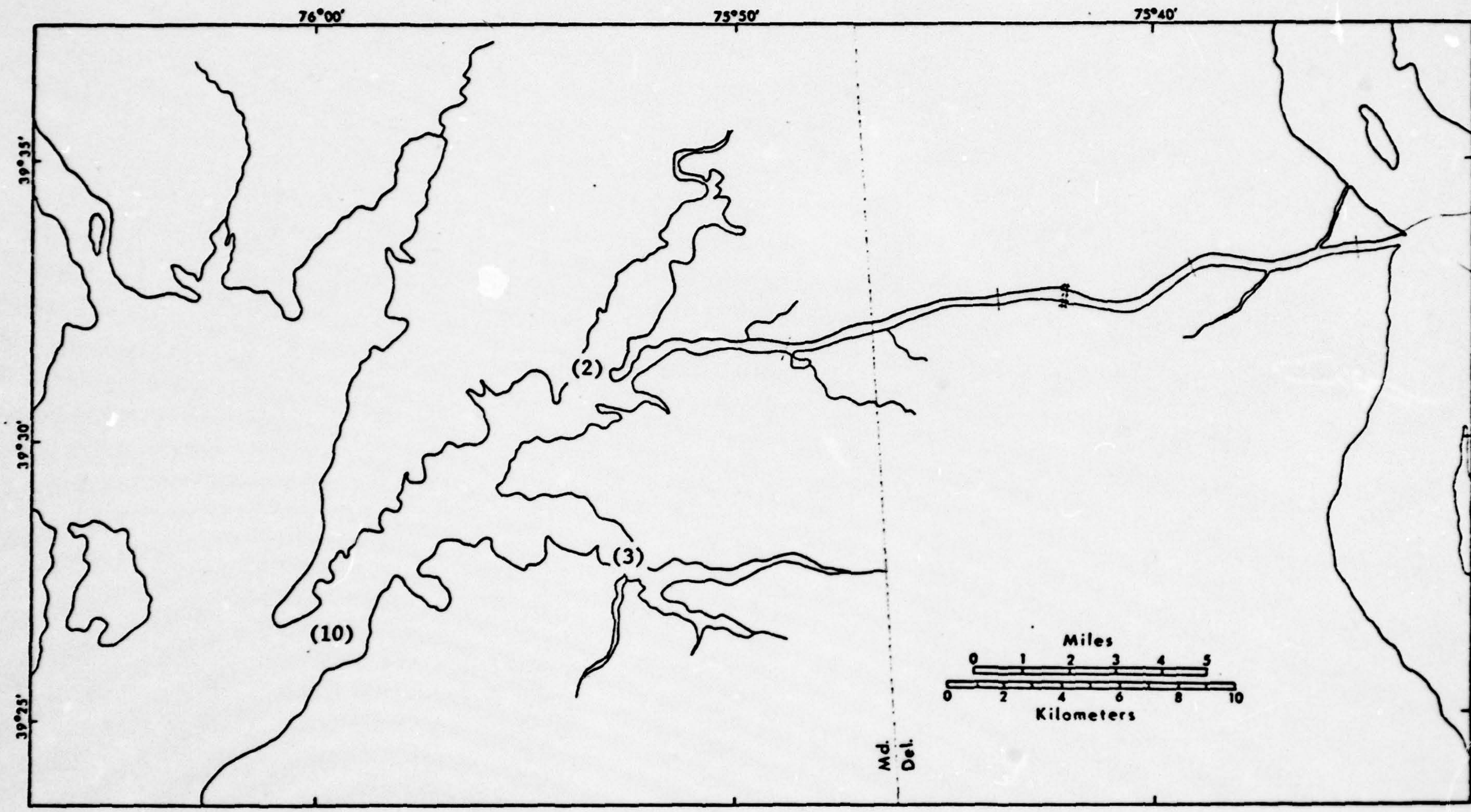


Figure 20. Map of release sites of tagged channel catfish, N= 22, 1972.

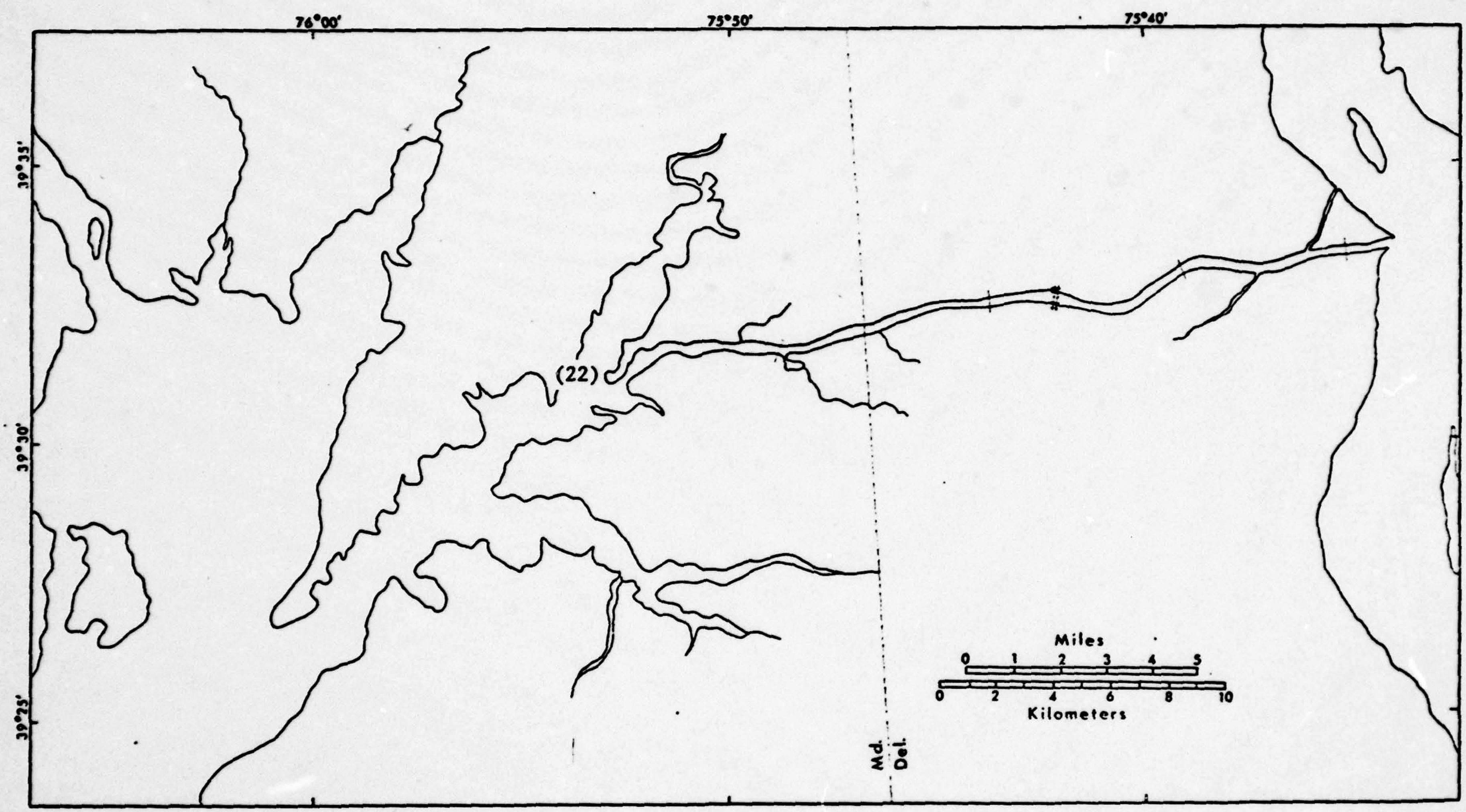


Figure 21. Map of release sites of tagged white catfish, N= 2, 1972.

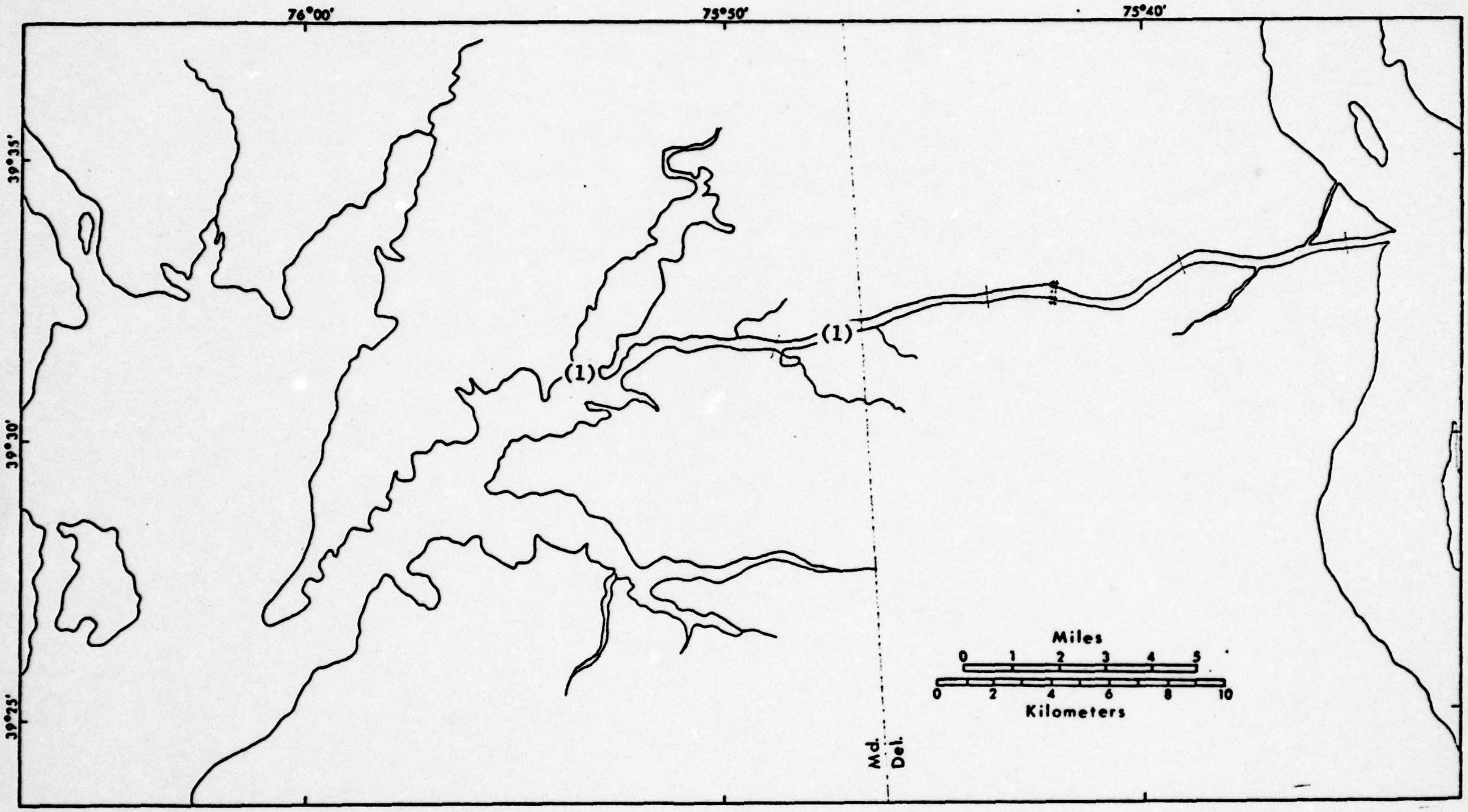


Figure 22. Map of release sites of tagged brown bullhead, N= 62, 1972.

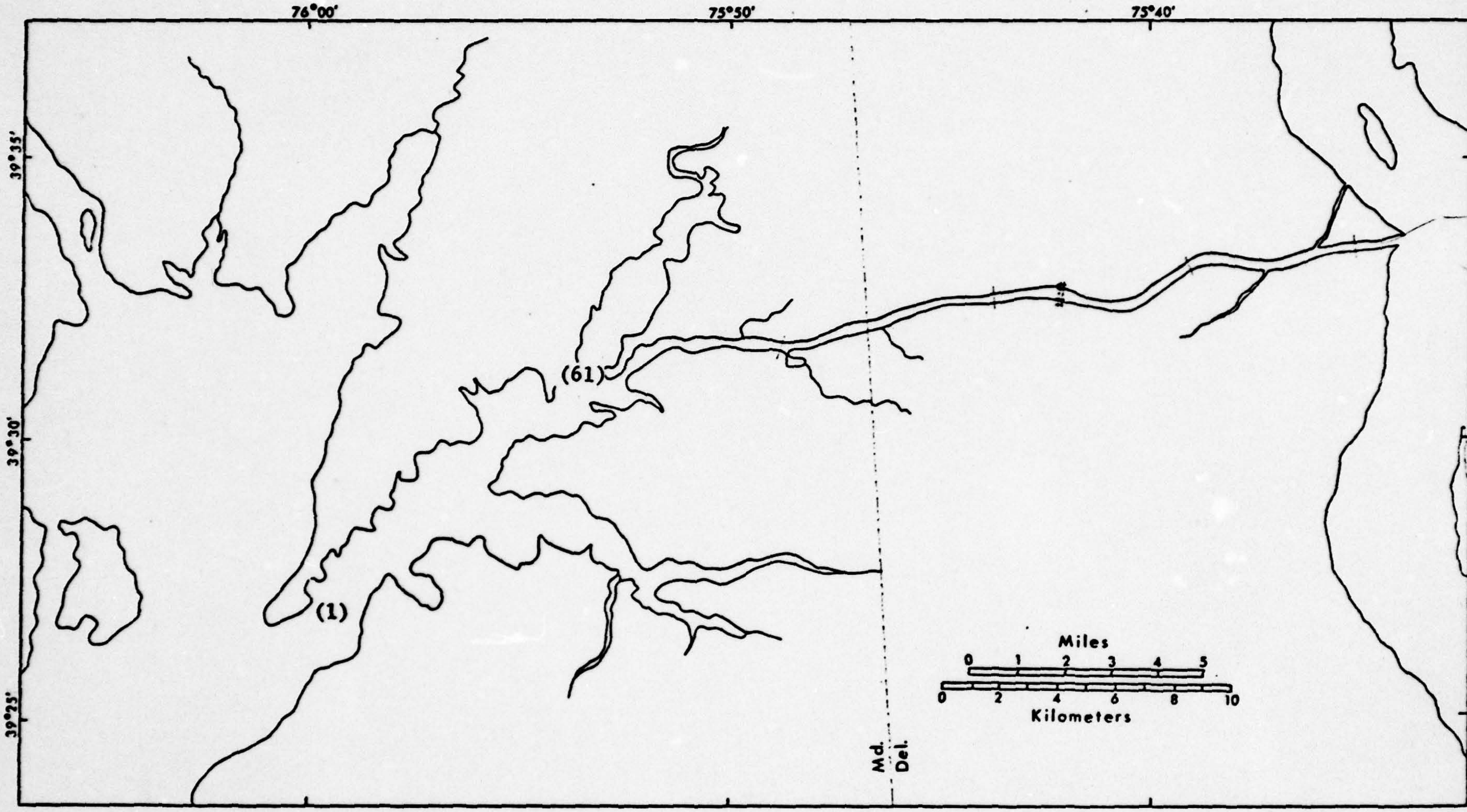


Figure 23. Map of release sites of tagged alewife, N= 12, 1972.

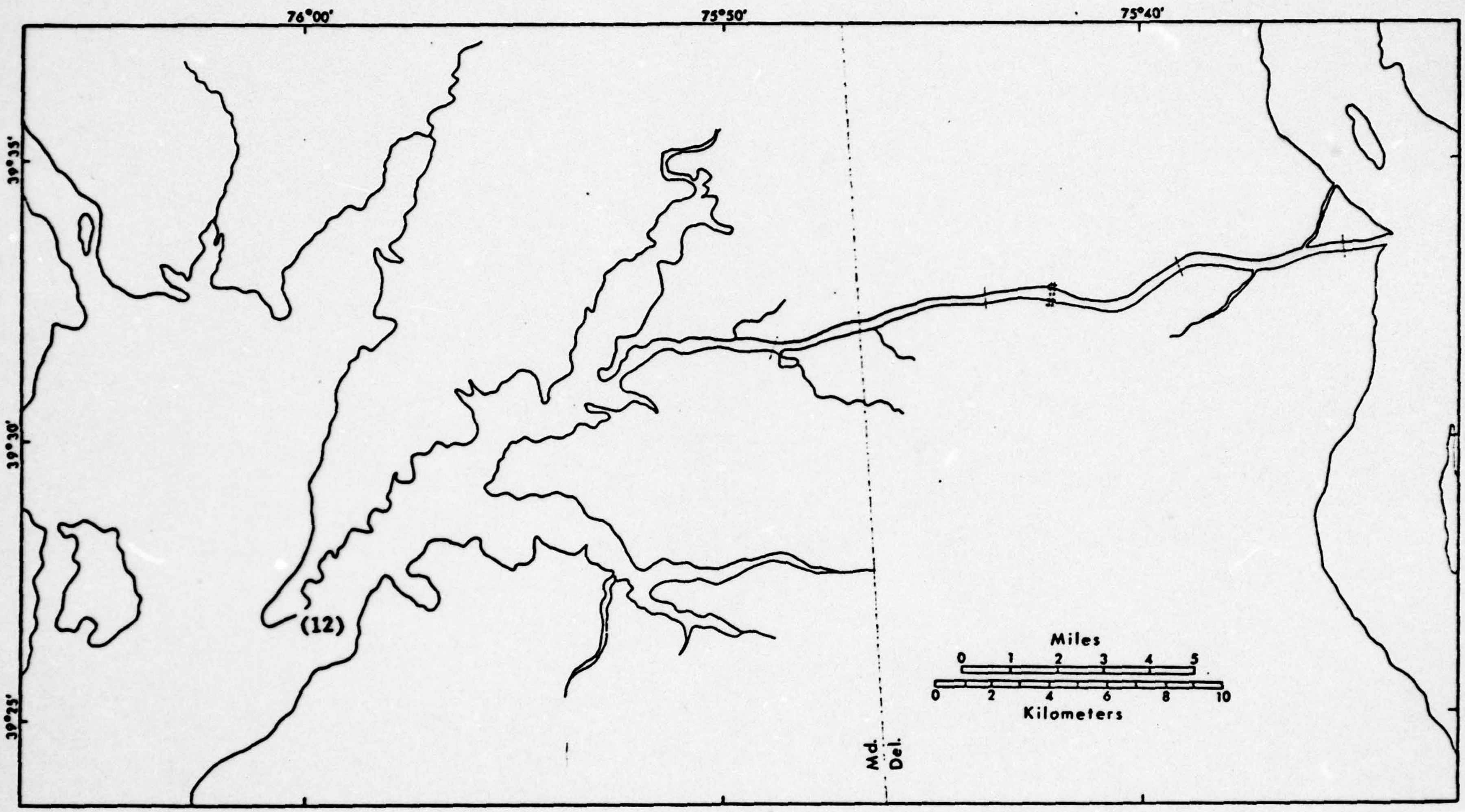


Figure 24. Map of release sites of tagged American shad, N= 17, 1972.

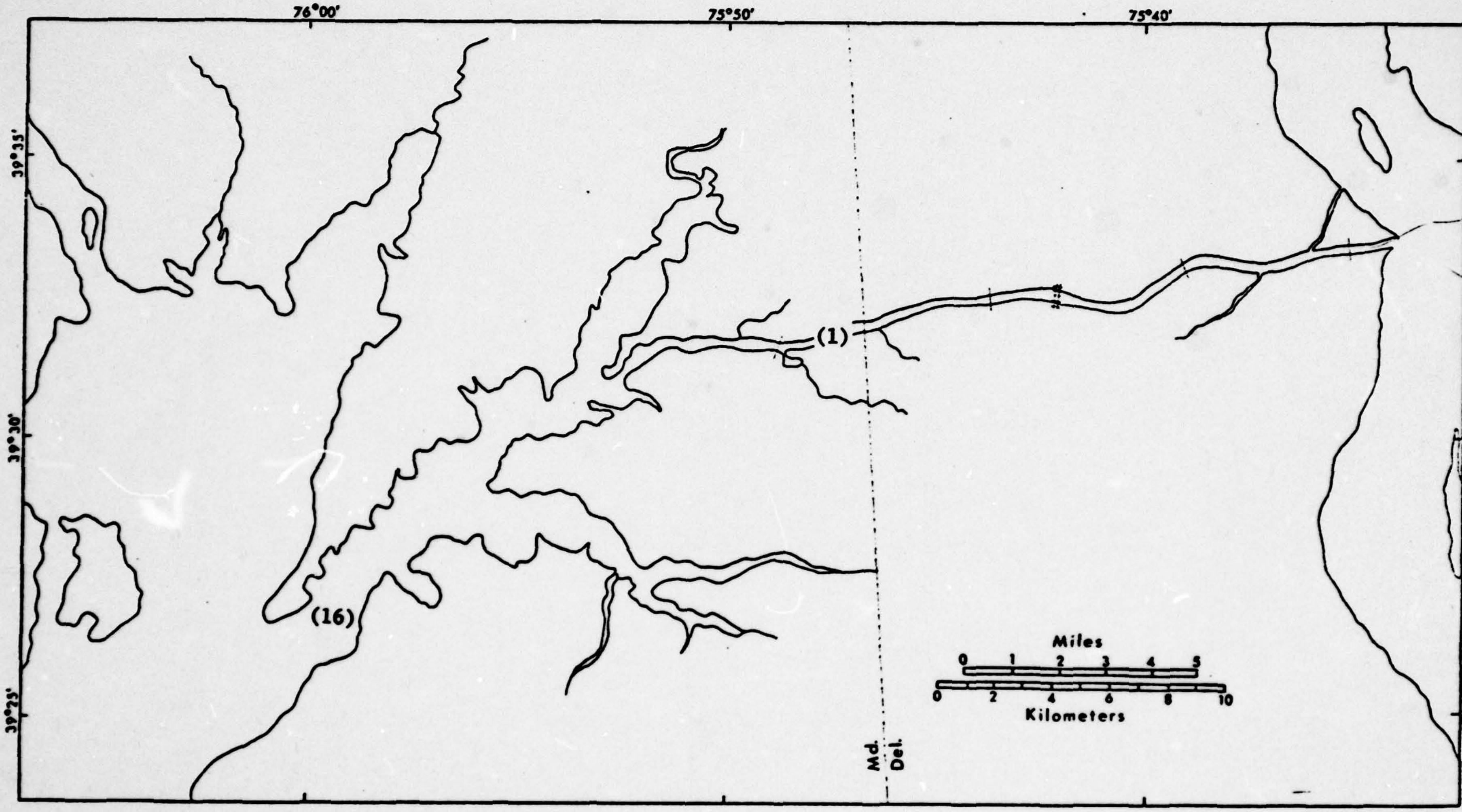


Figure 25. Map of release sites of tagged hickory shad, N= 22, 1972.

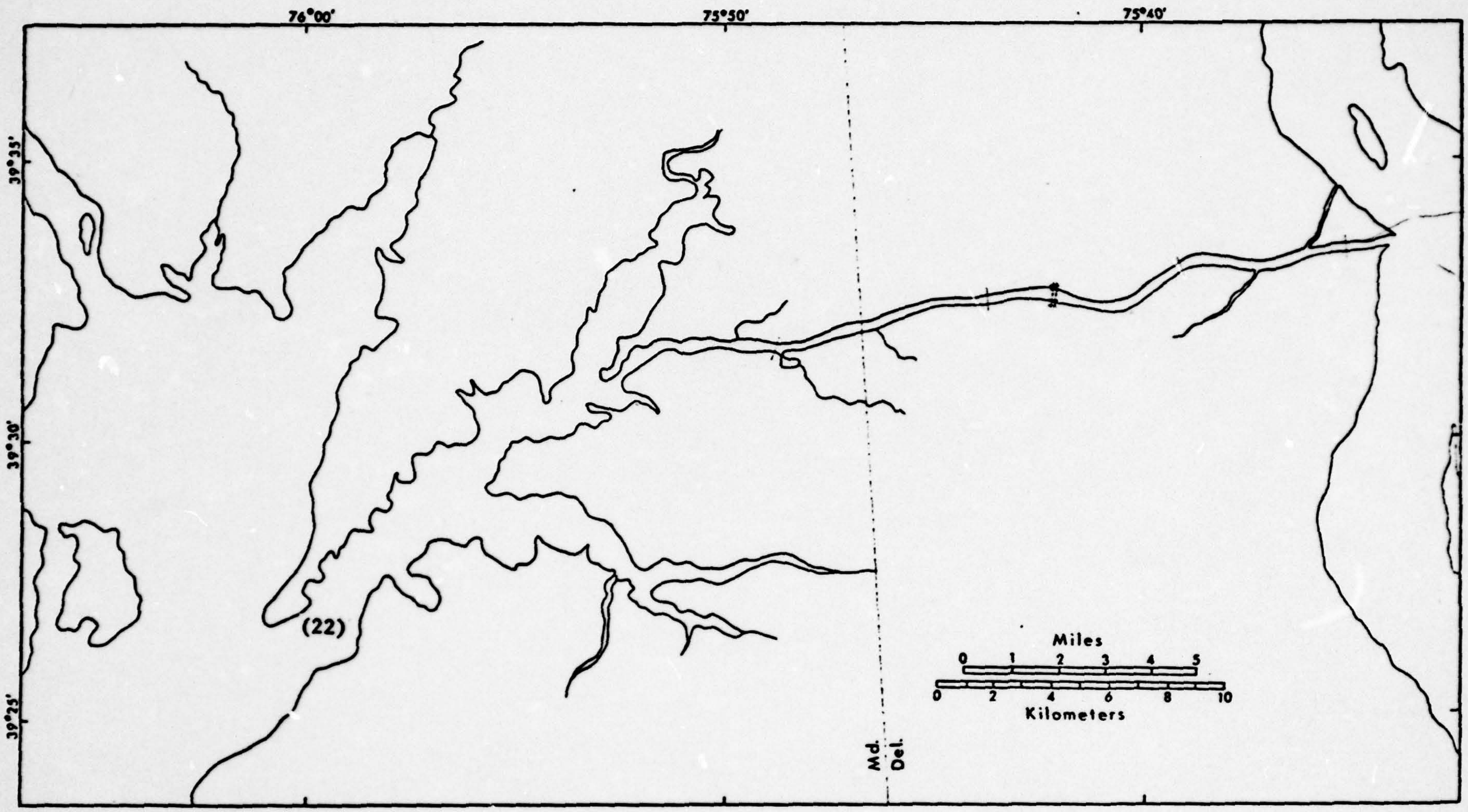
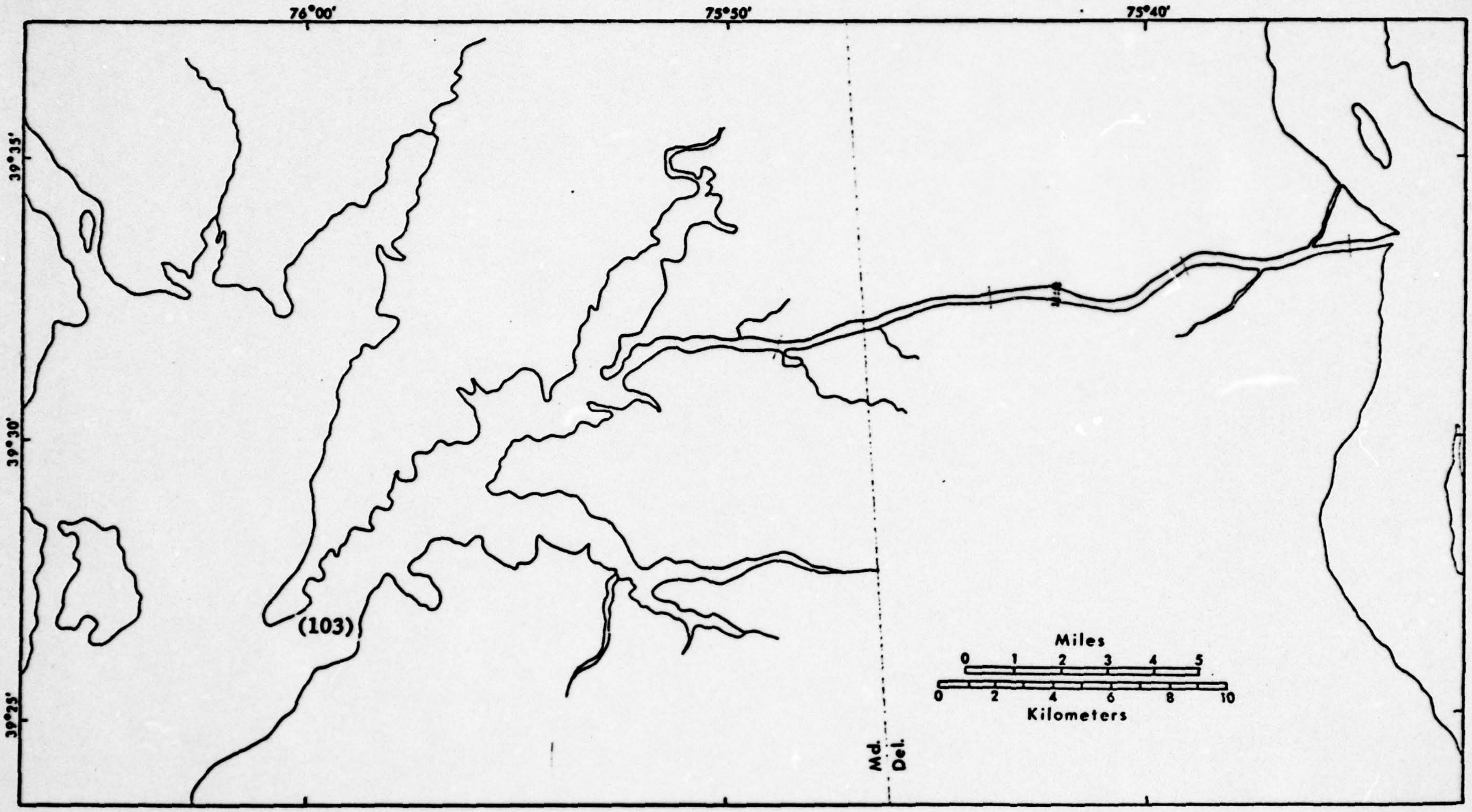


Figure 26 Map of release sites of tagged striped bass, N= 103, 1973.



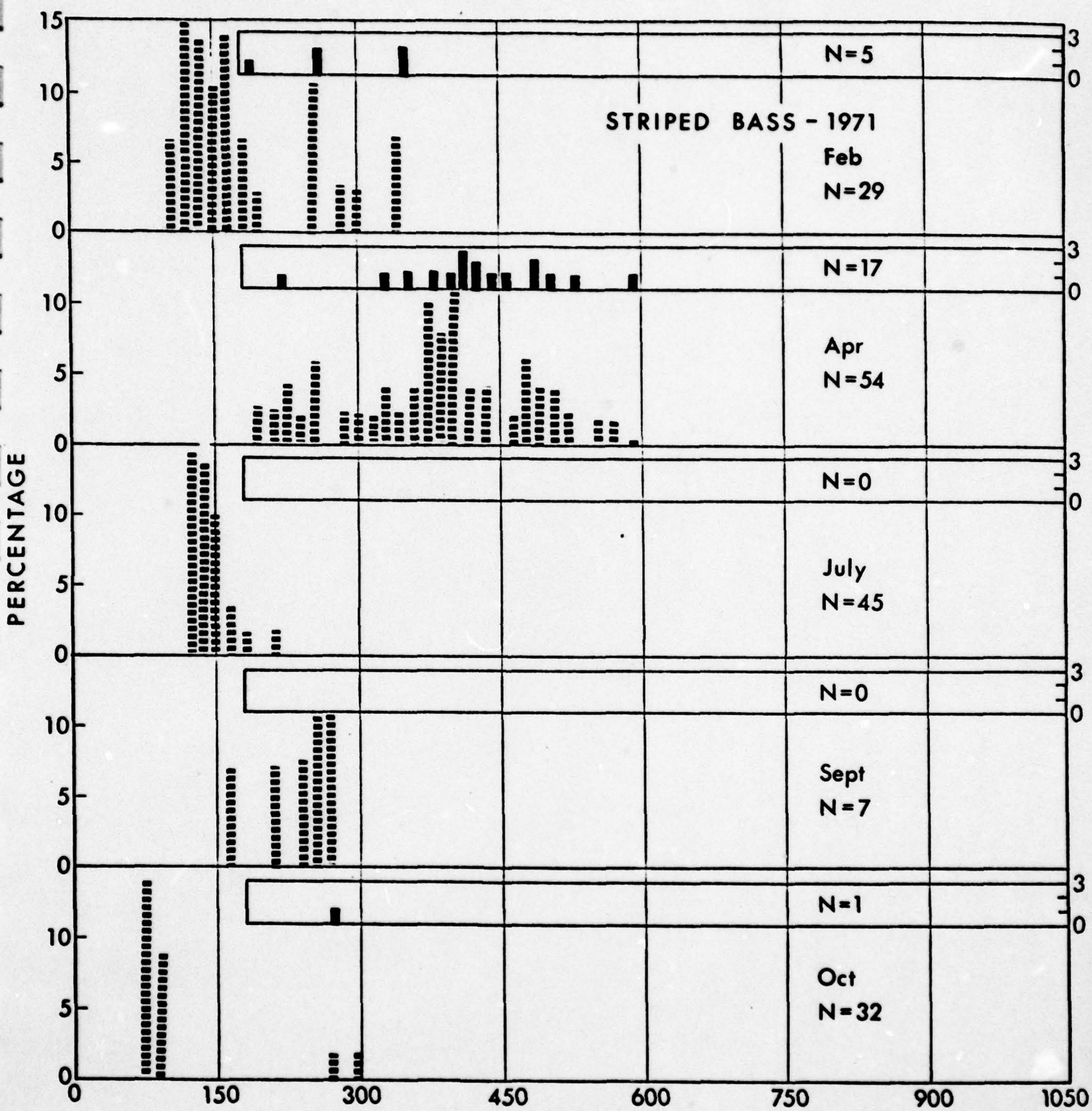


Fig. 27-A. FORK LENGTH FREQUENCY by 15 mm GROUPS

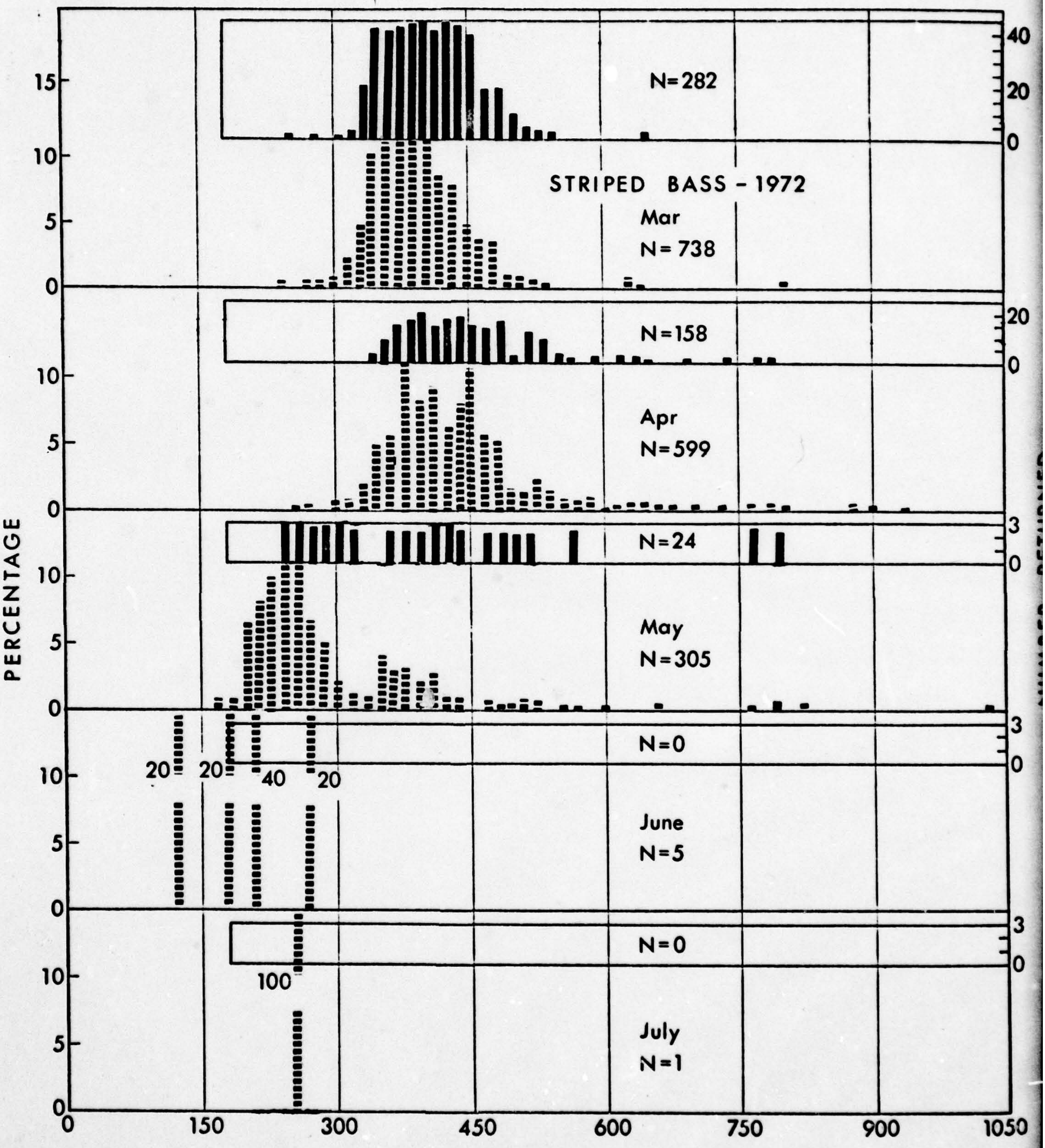


Fig. 27-B. FORK LENGTH FREQUENCY by 15 mm GROUPS

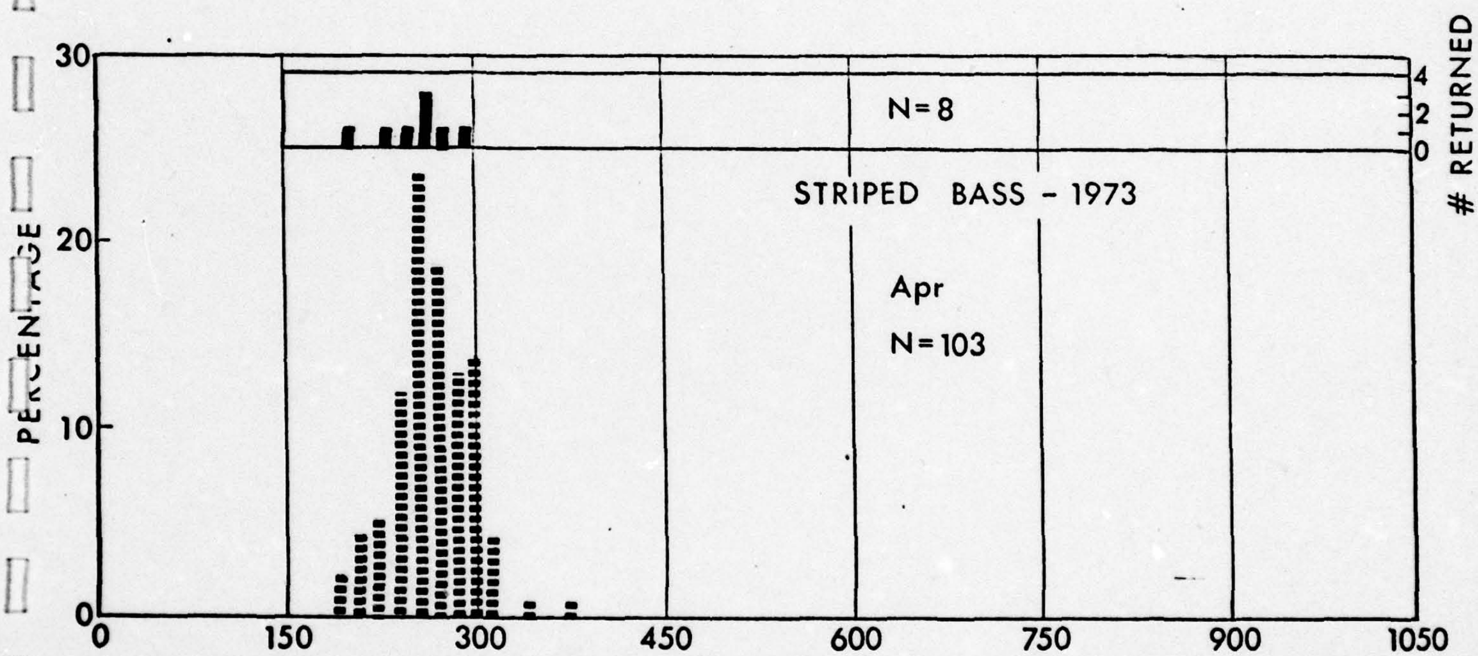


Fig. 27-C. FORK LENGTH FREQUENCY by 15mm GROUPS

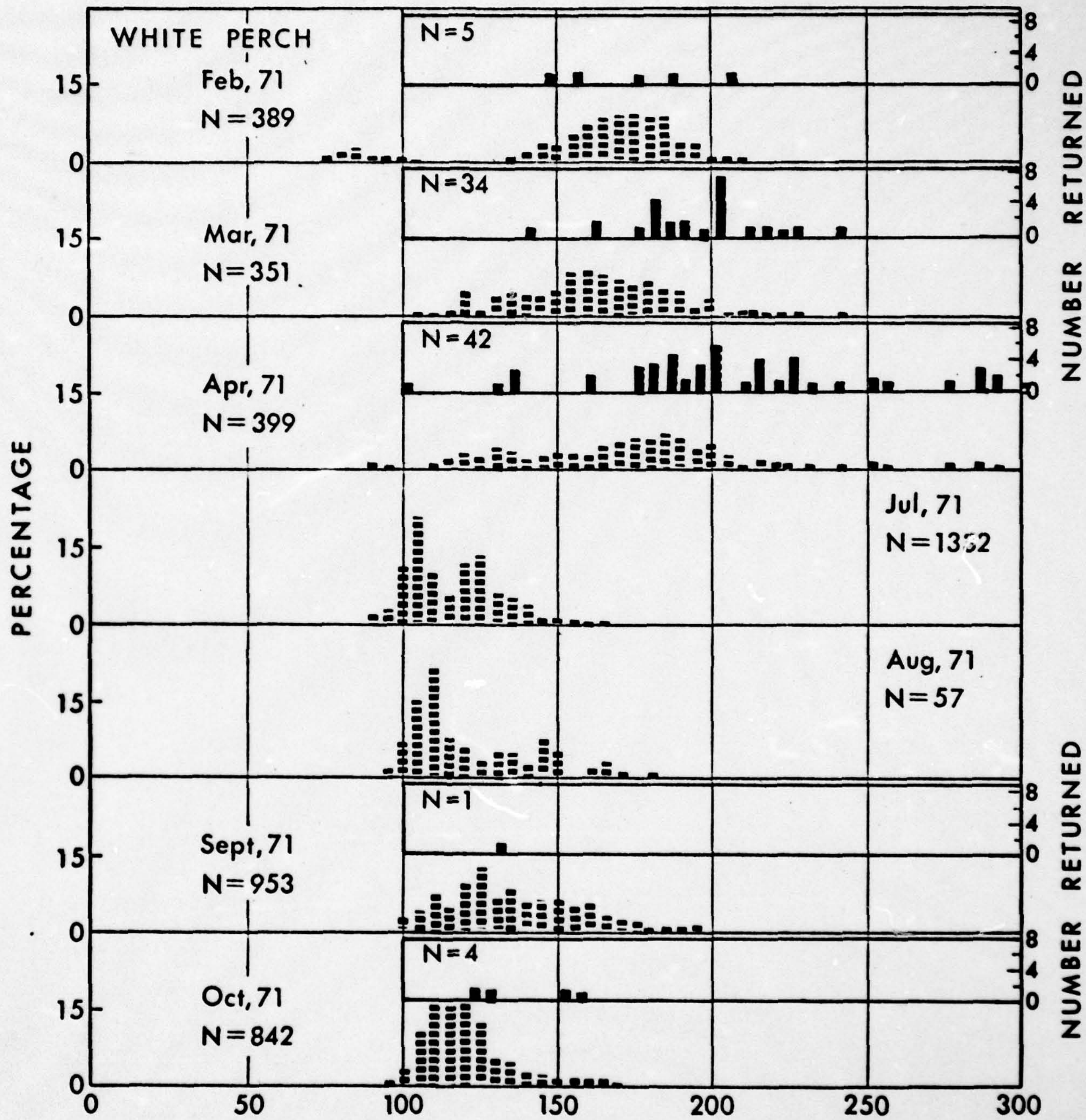


Fig. 28-A. FORK LENGTH FREQUENCY by 5mm GROUPS

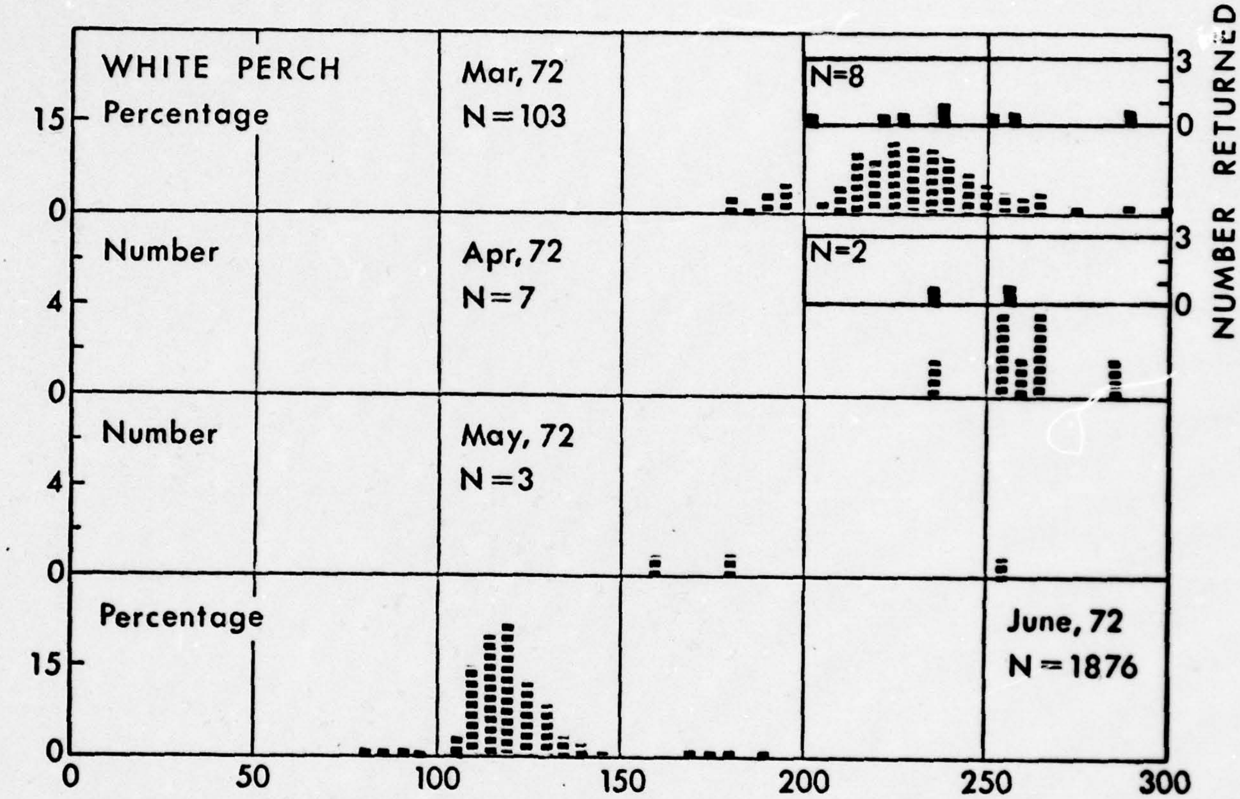


Fig. 28-B. FORK LENGTH FREQUENCY by 5mm GROUPS

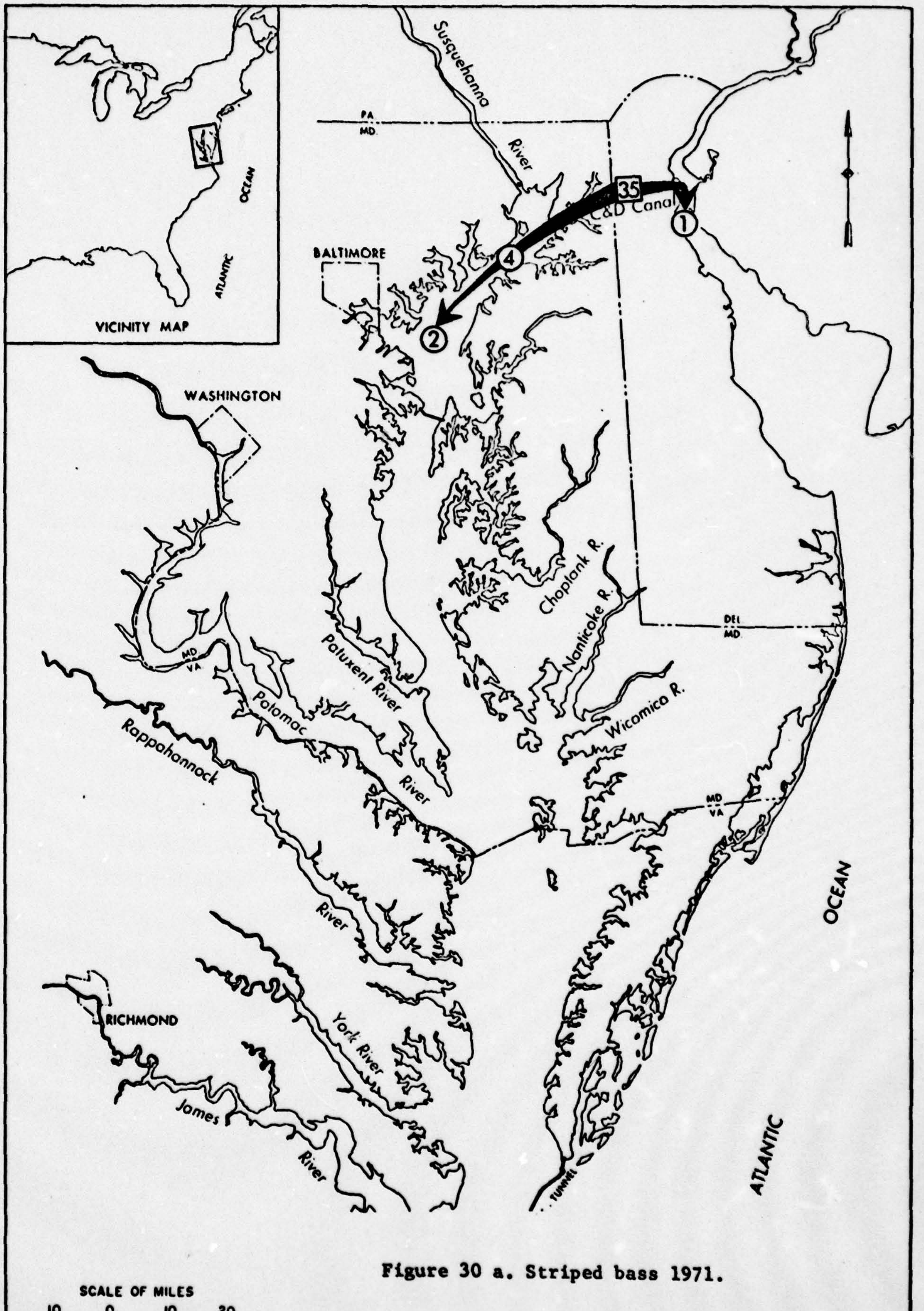


Figure 30 a. Striped bass 1971.

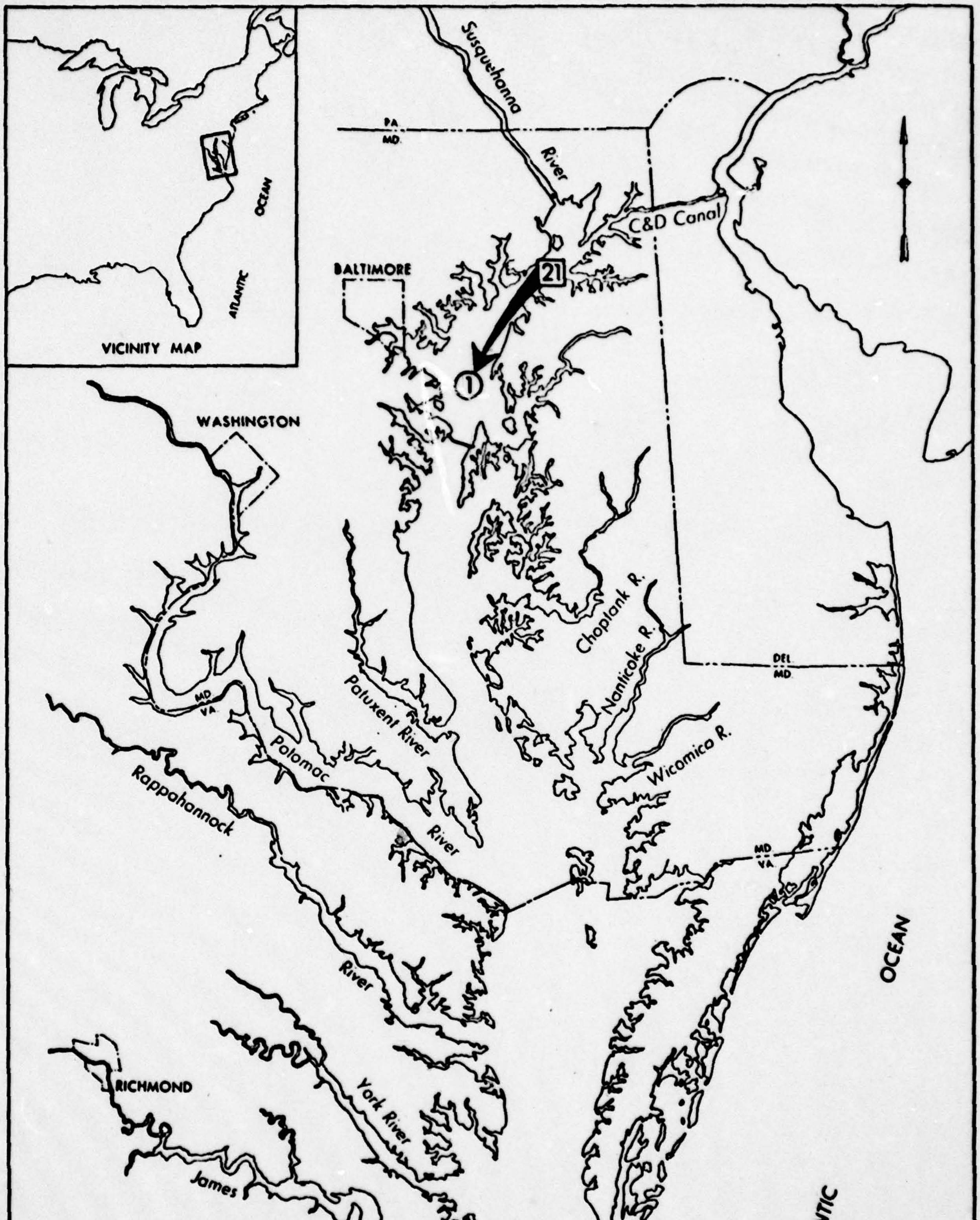


Figure 30 b. Striped bass 1971.

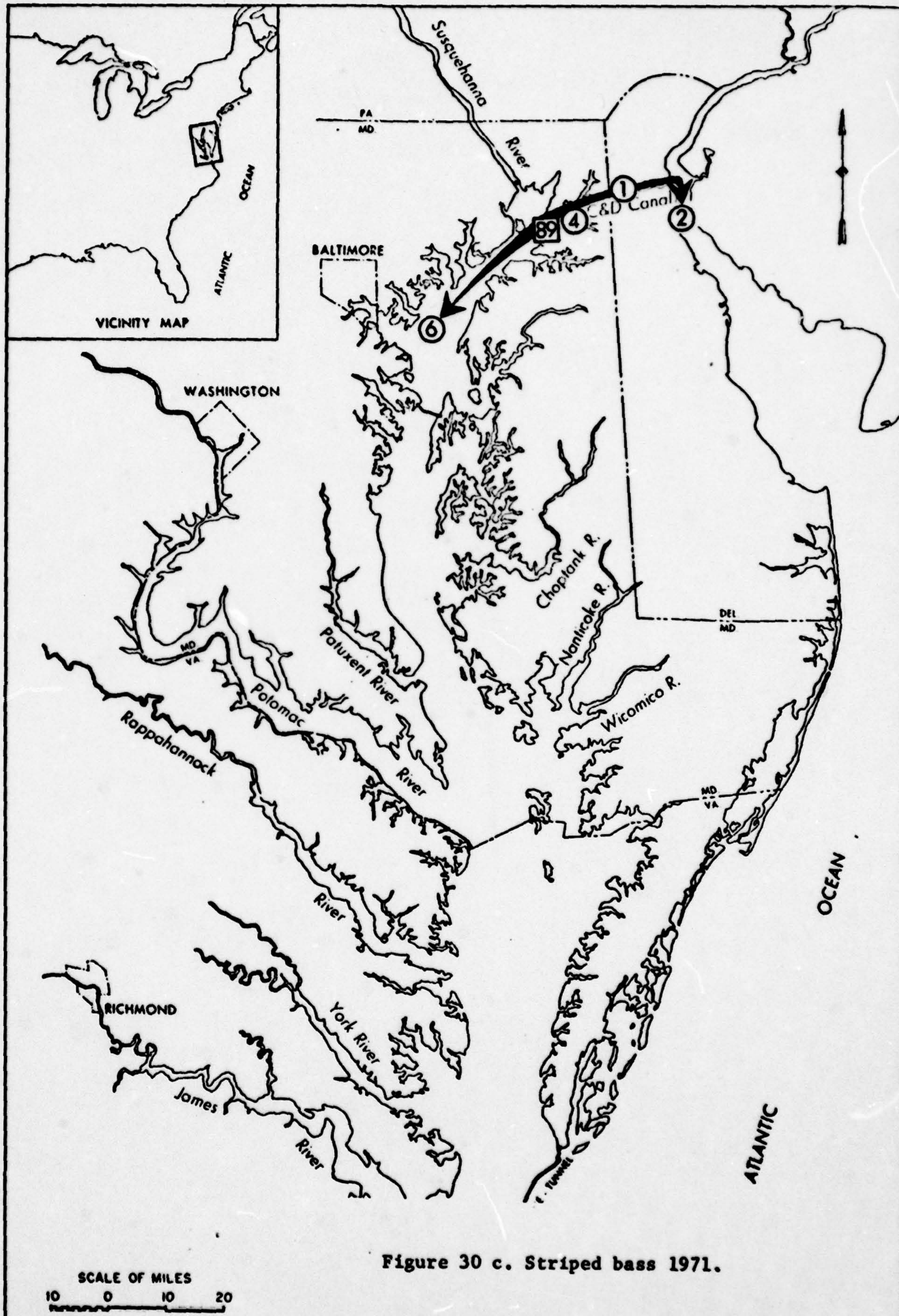


Figure 30 c. Striped bass 1971.

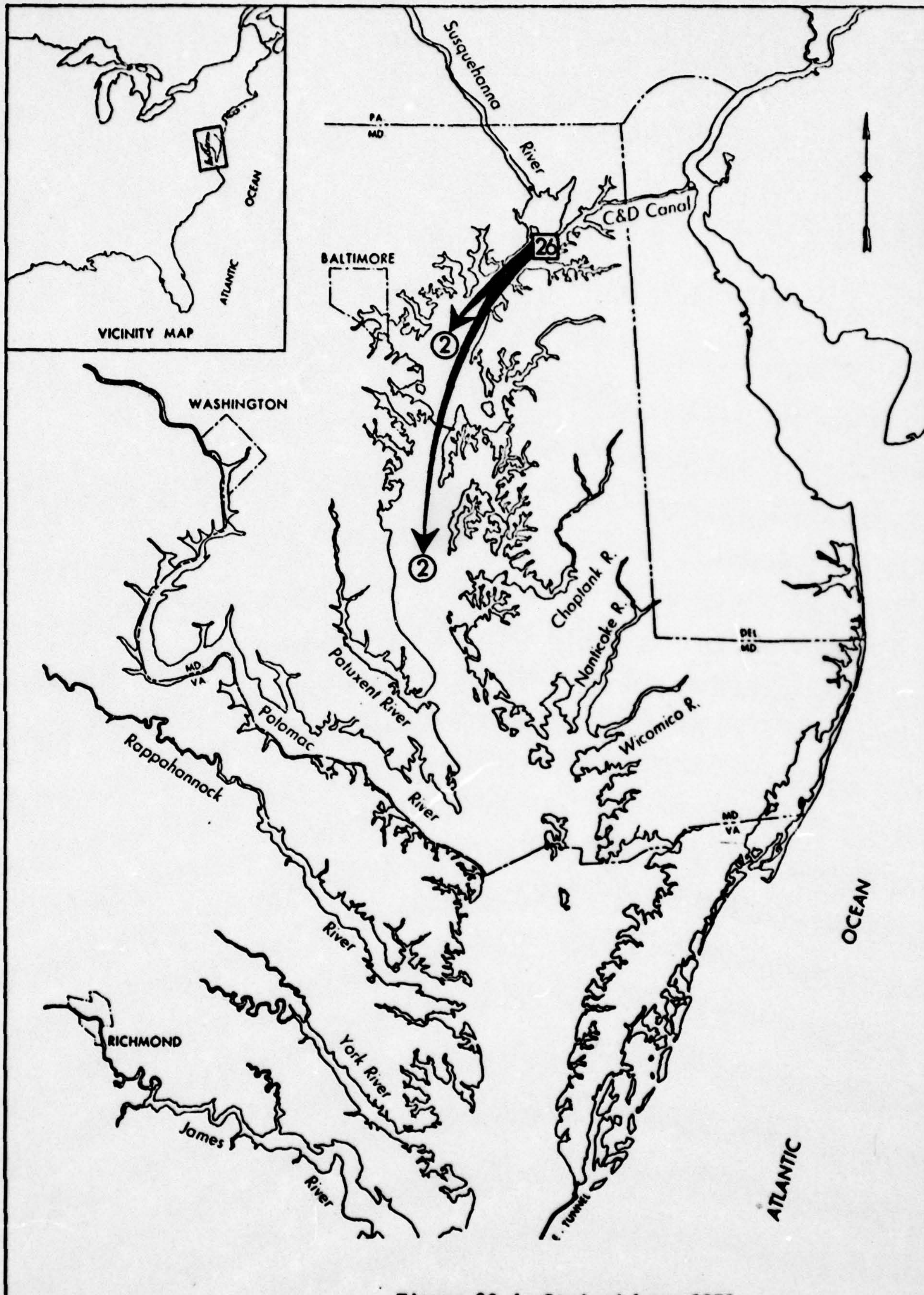


Figure 30 d. Striped bass 1971.

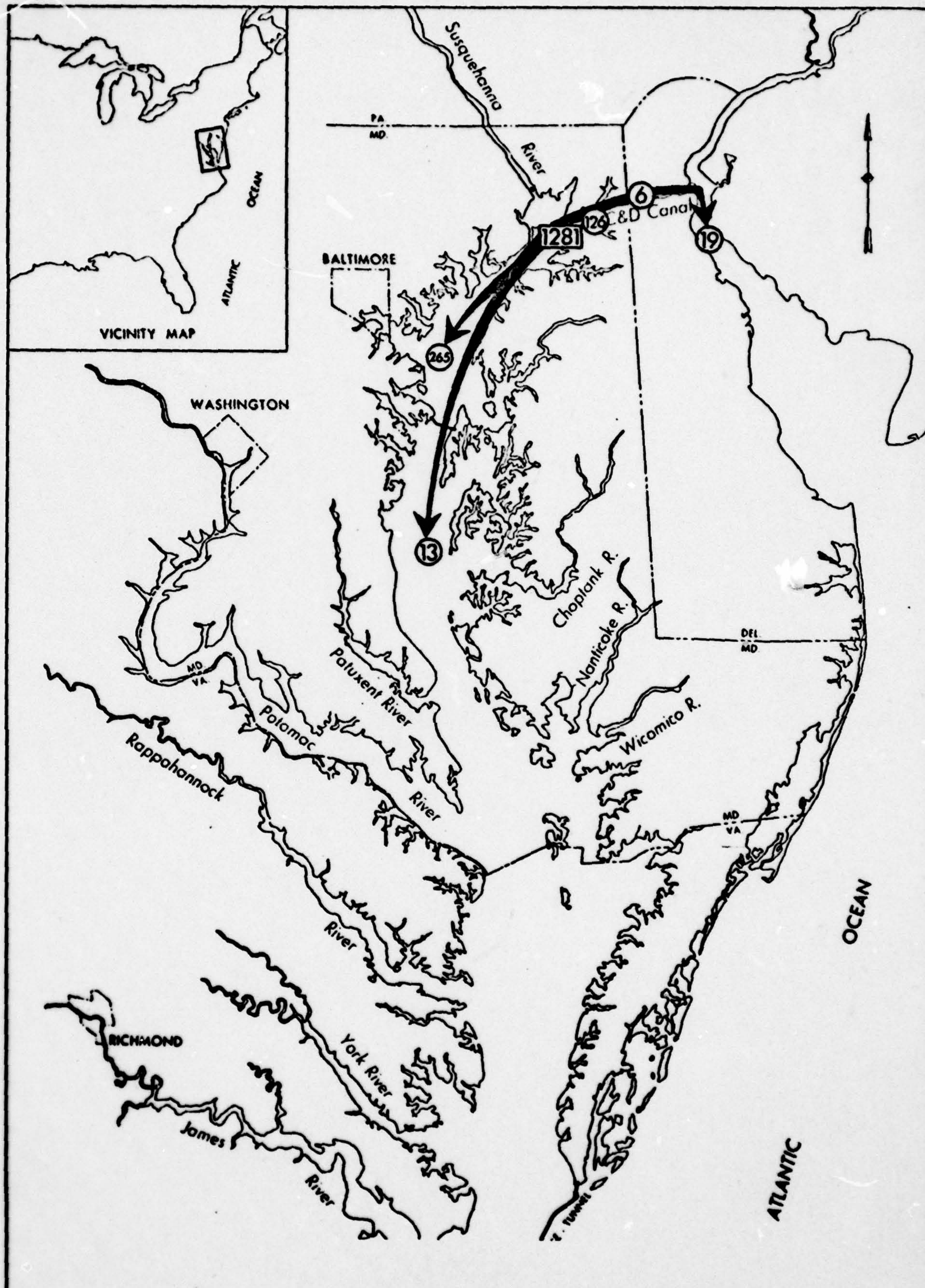


Figure 30 e. Striped bass 1972.

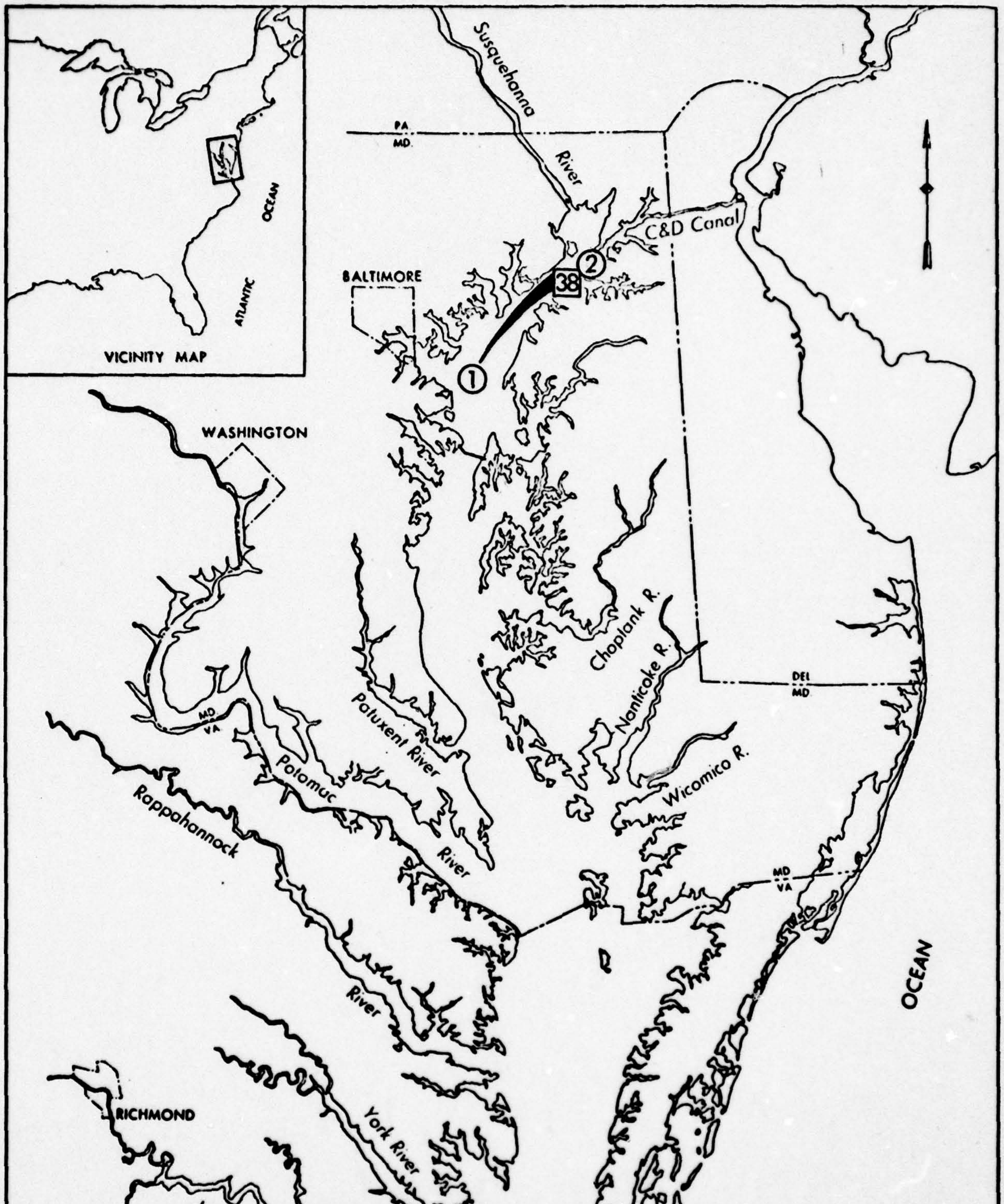


Figure 30 f. Striped bass 1972.

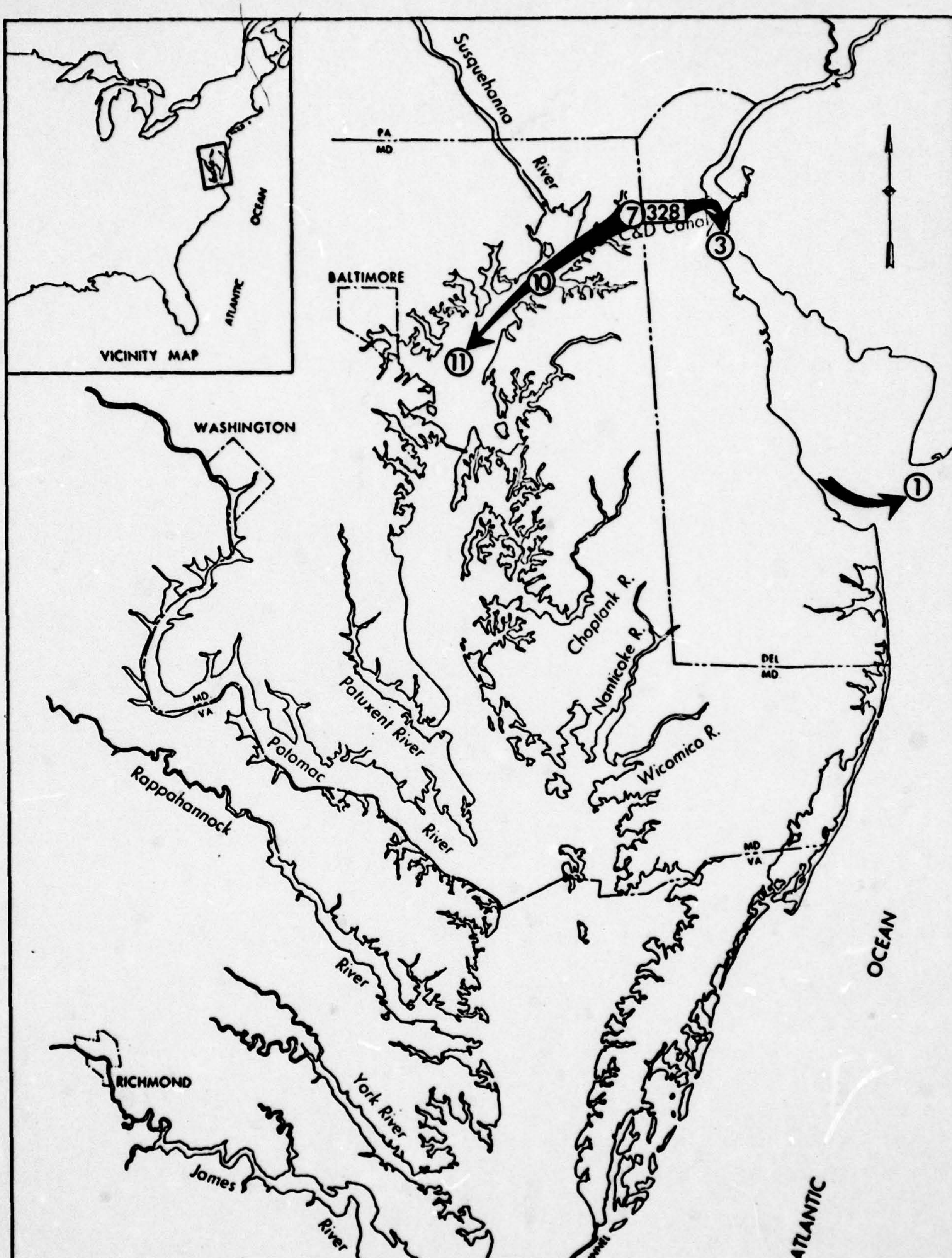


Figure 30 g. Striped bass 1972.

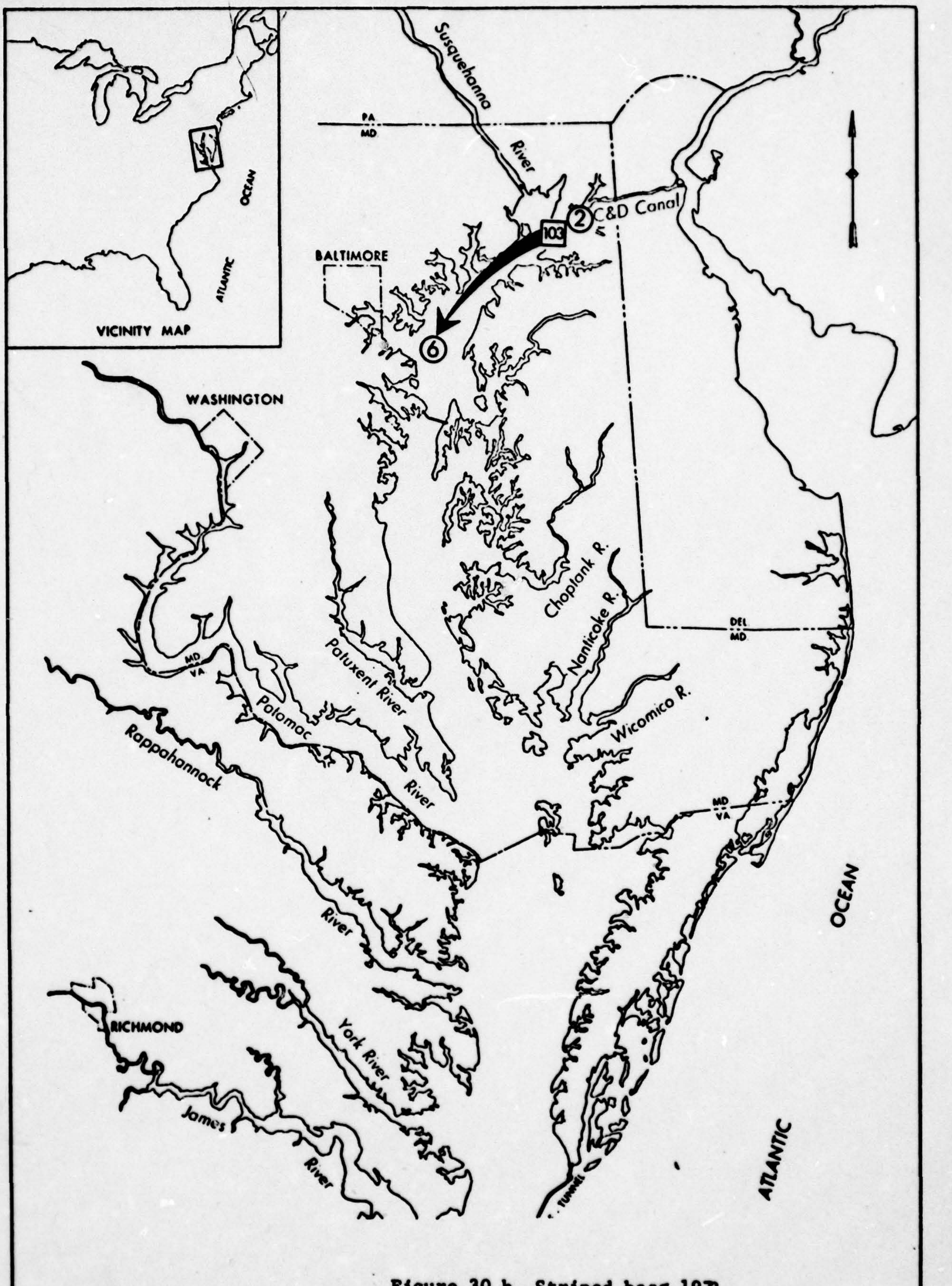


Figure 30 h. Striped bass 1973.

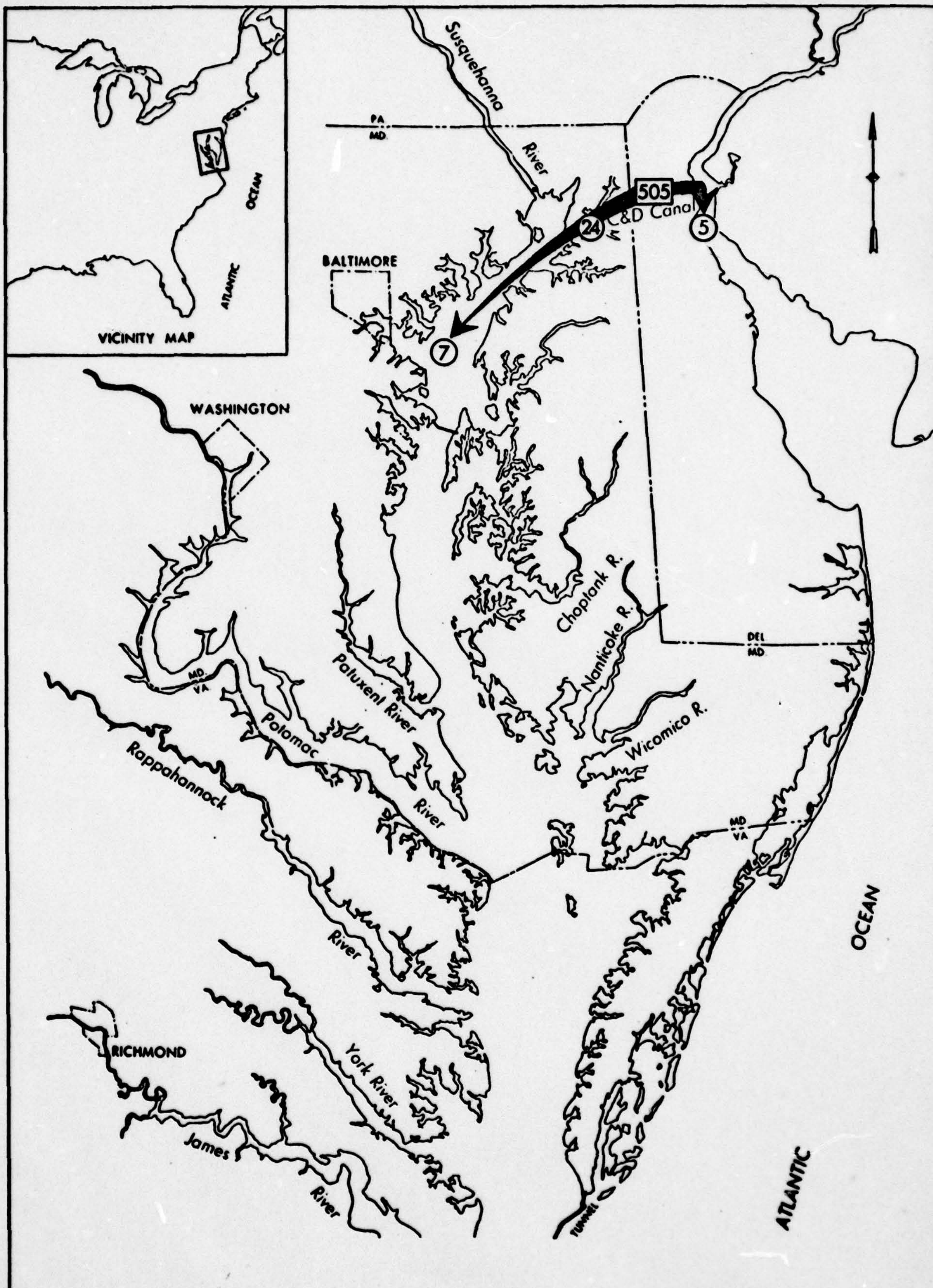


Figure 30 i. White perch 1971.

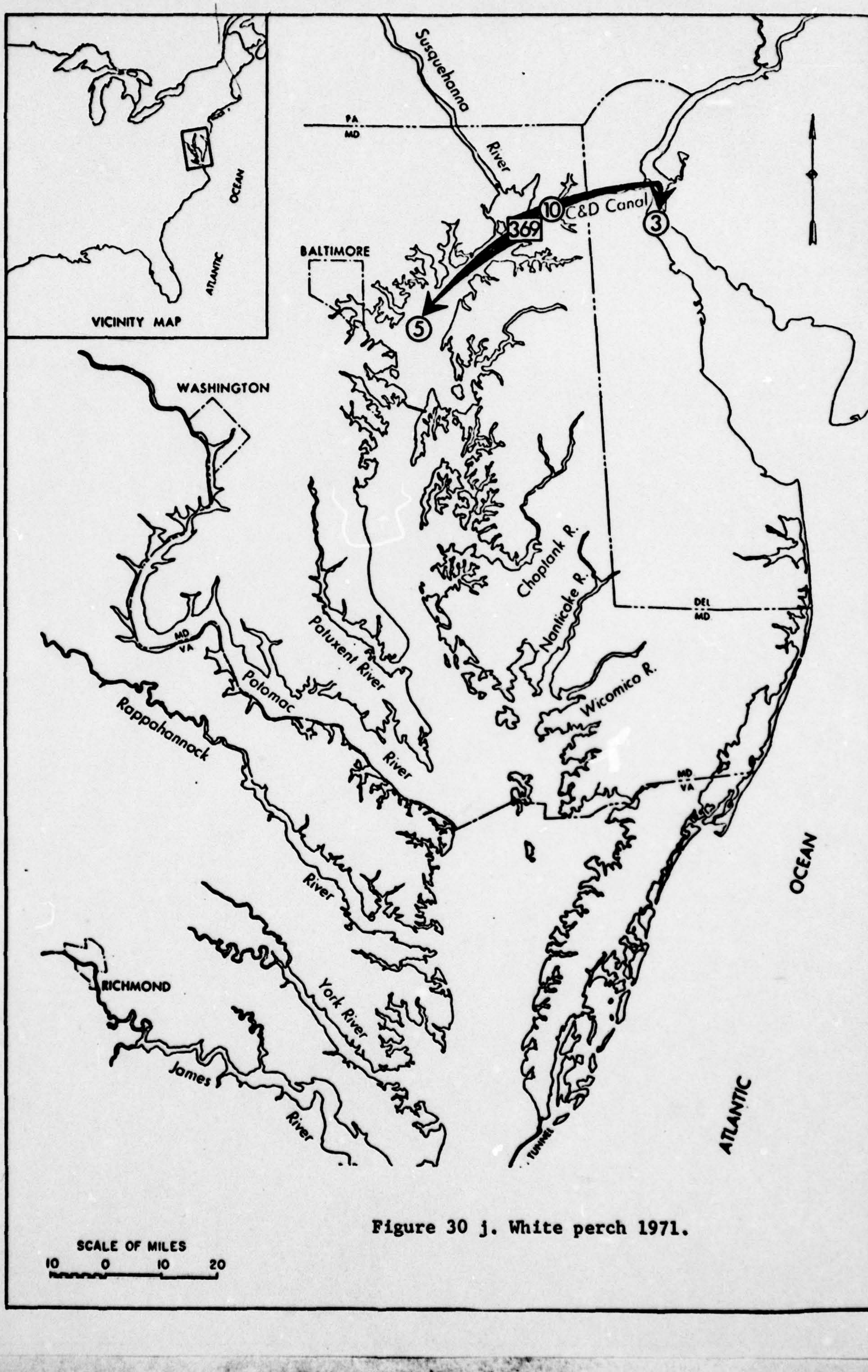


Figure 30 j. White perch 1971.

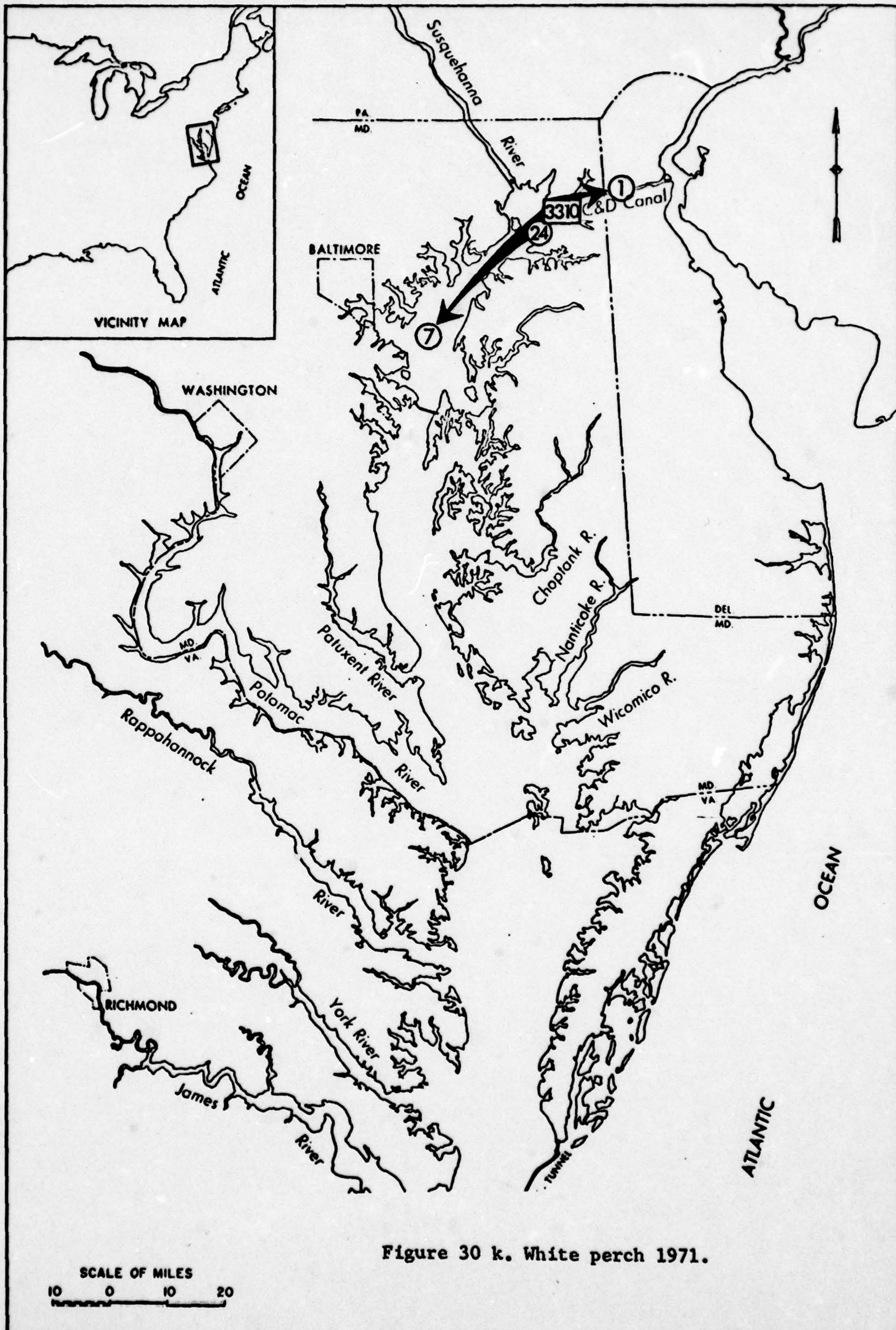


Figure 30 k. White perch 1971.

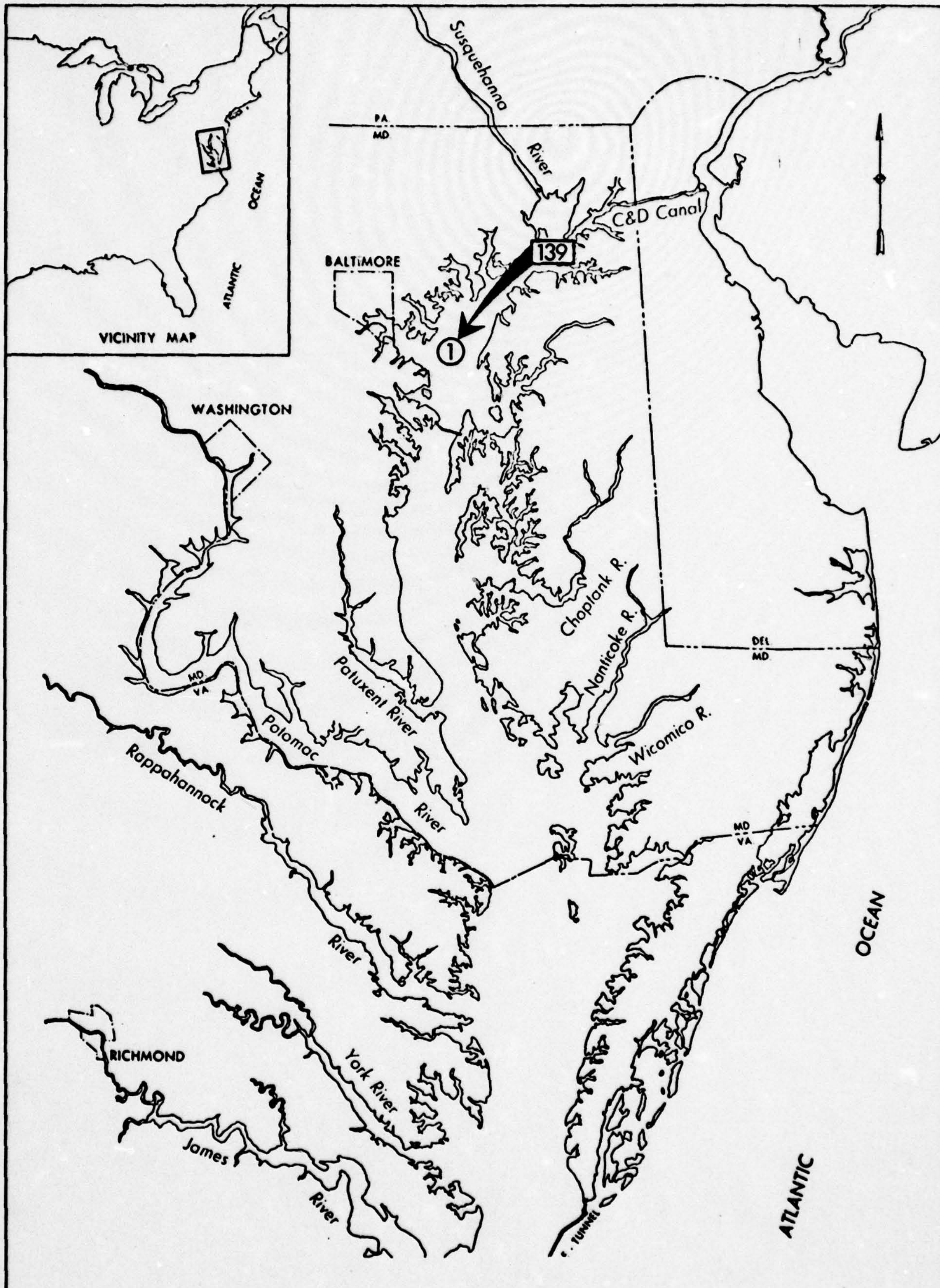


Figure 30 1. White perch 1971.

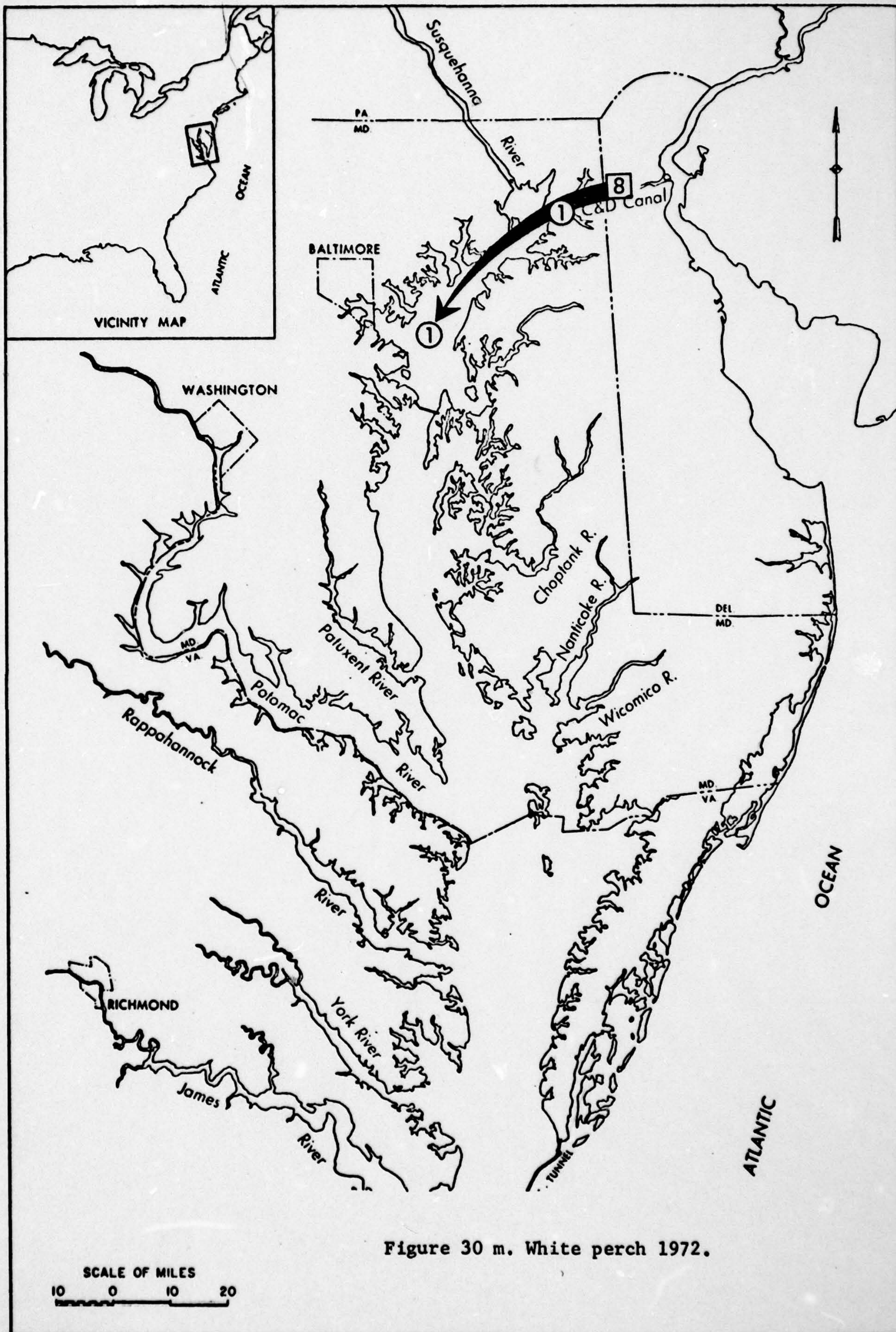


Figure 30 m. White perch 1972.

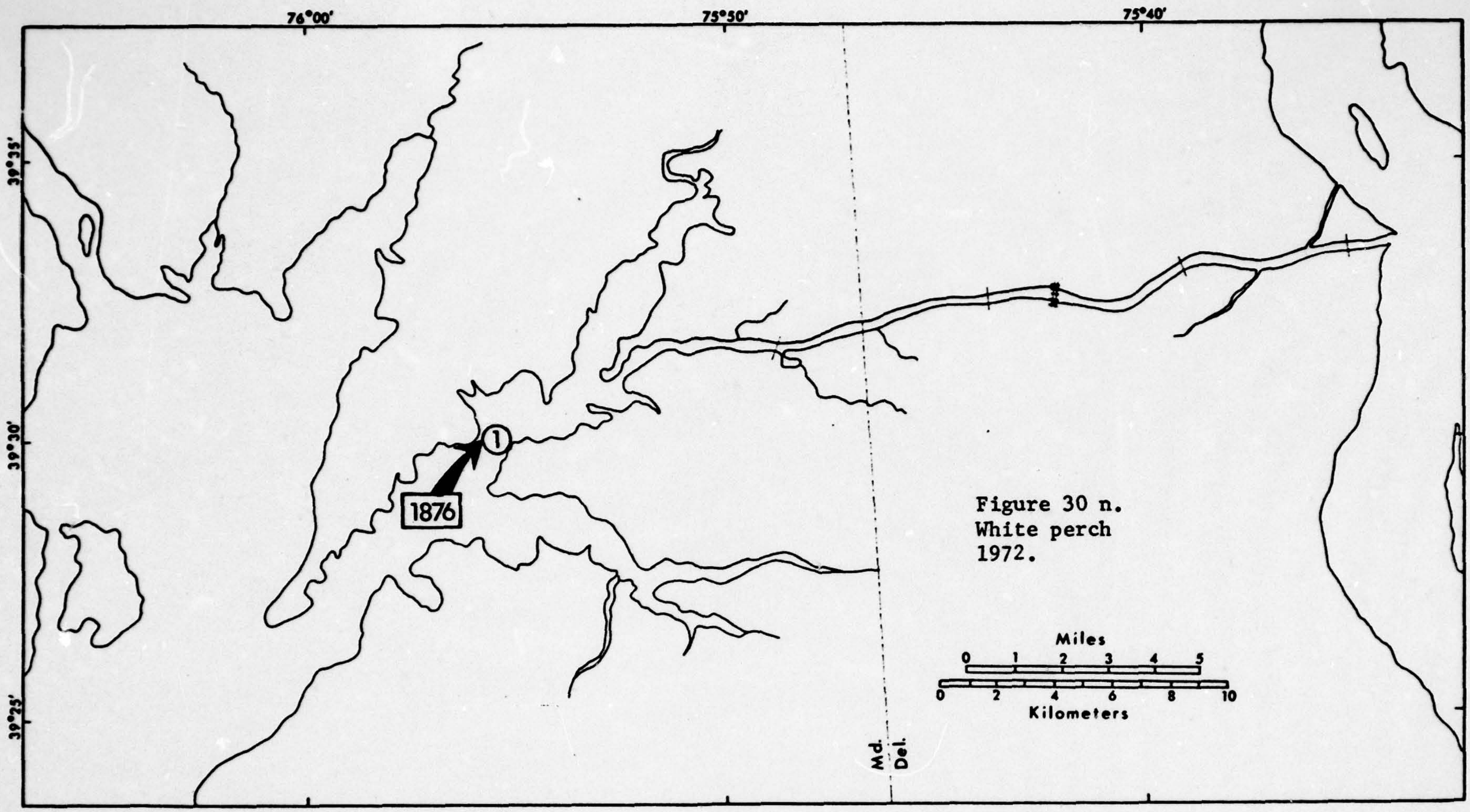


Figure 30 n.
White perch
1972.

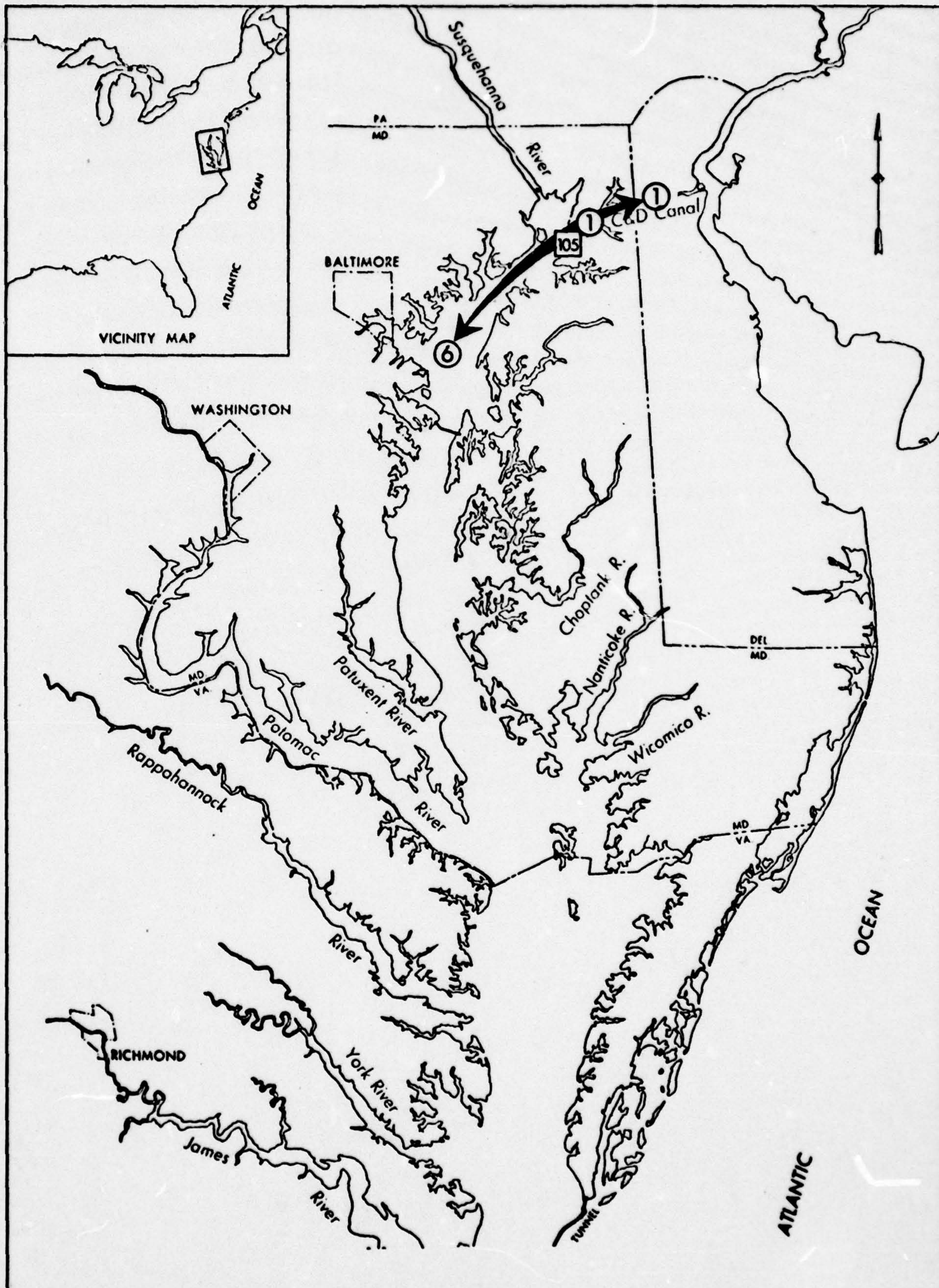


Figure 30 o. White perch 1972.

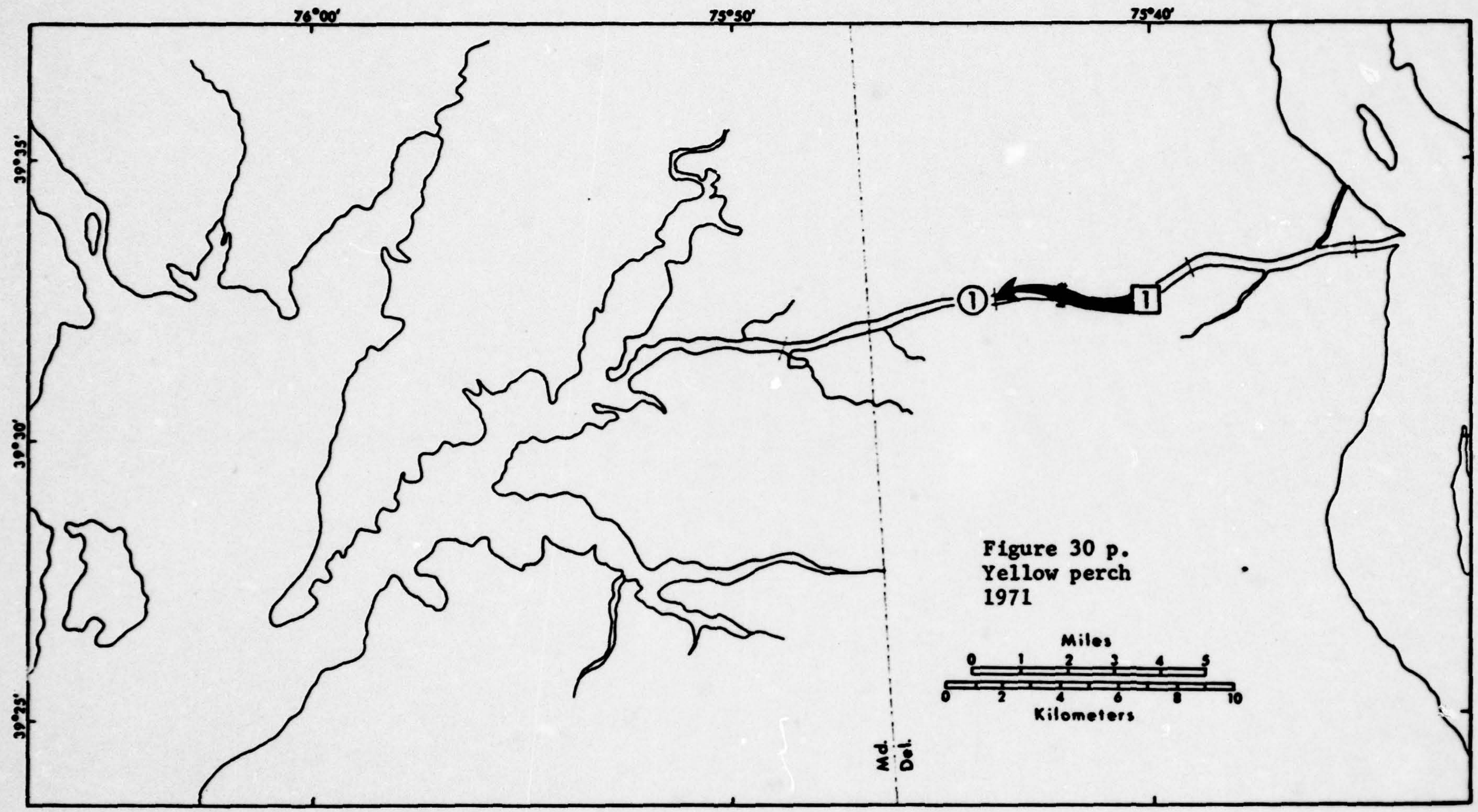


Figure 30 p.
Yellow perch
1971

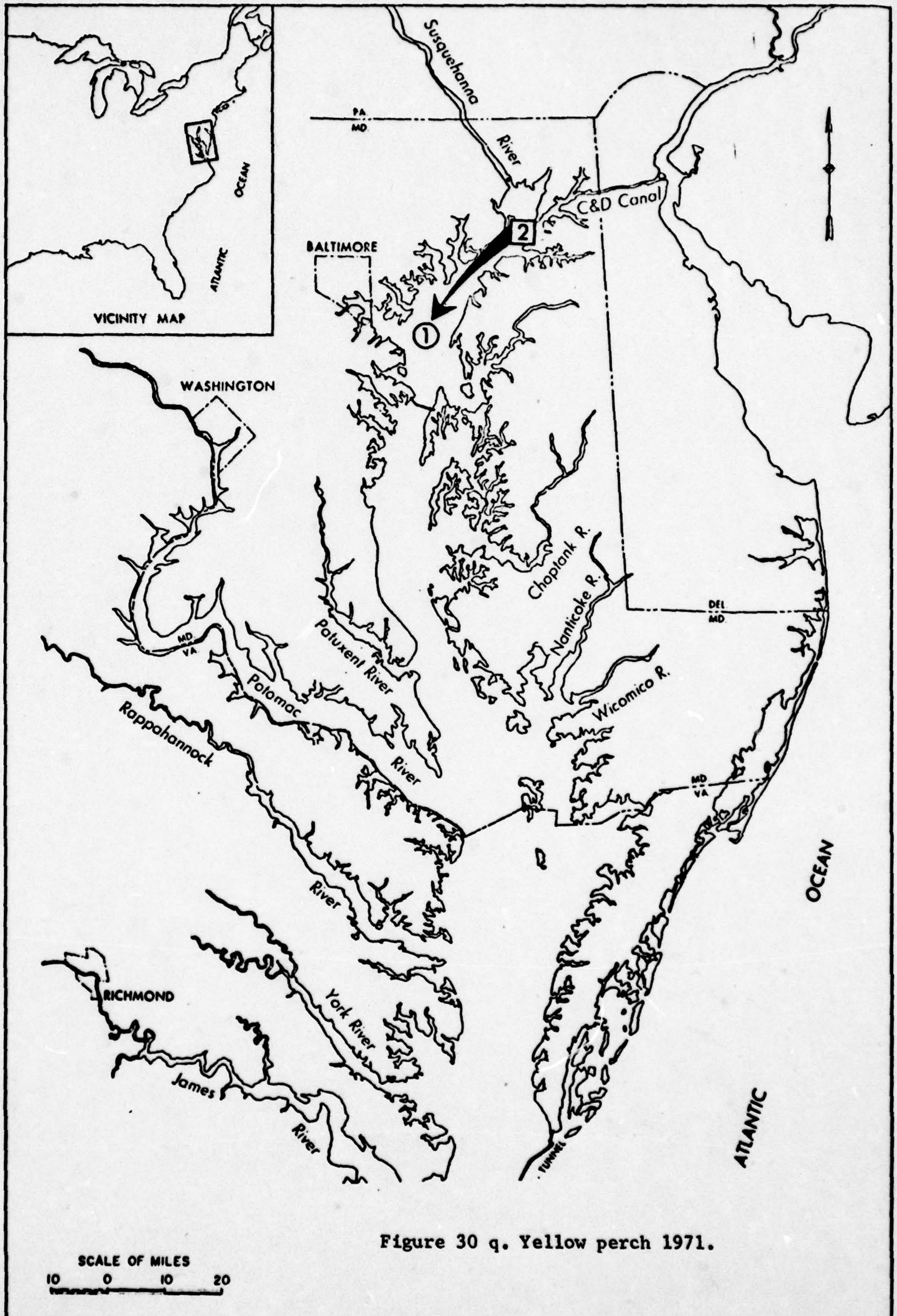


Figure 30 q. Yellow perch 1971.

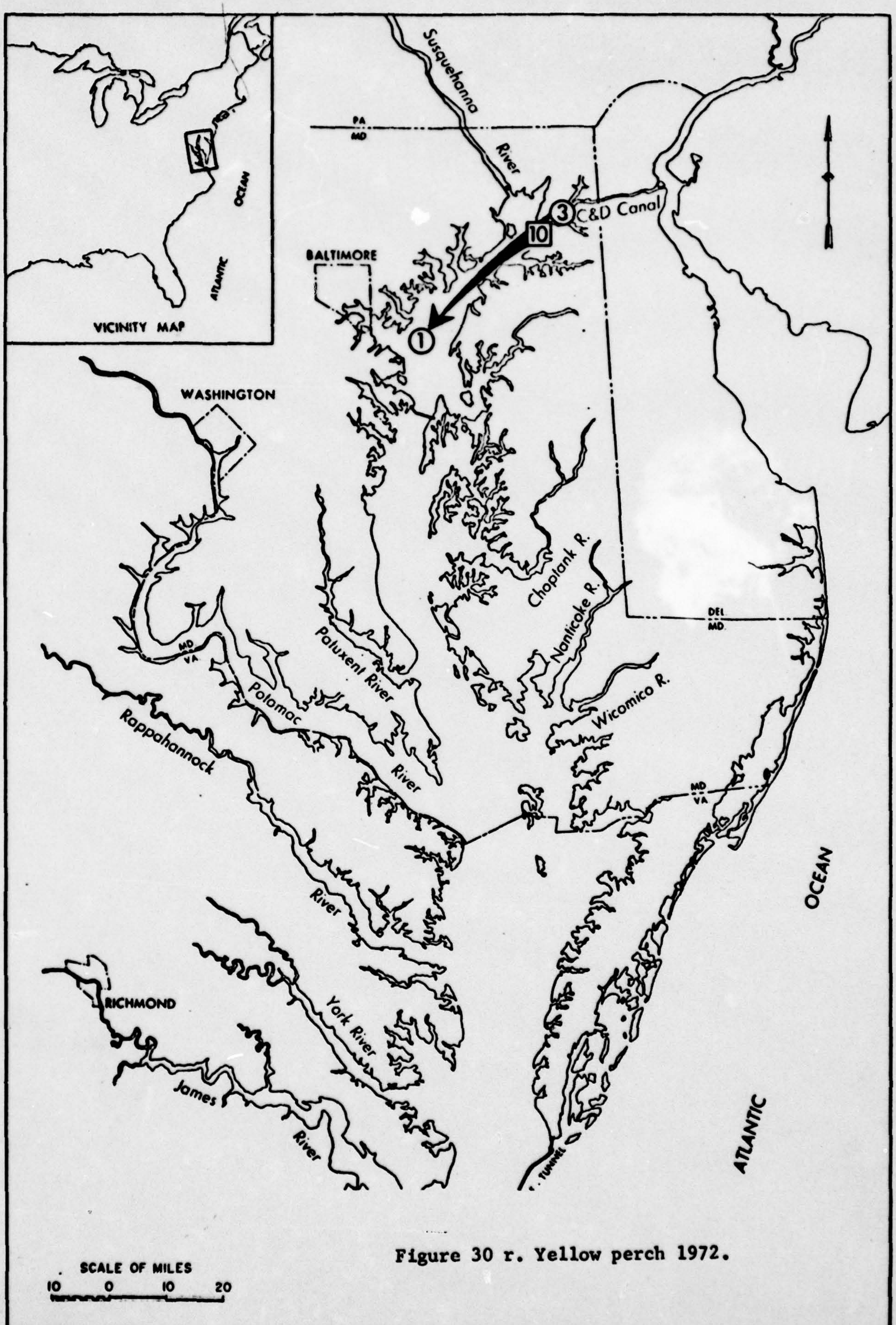


Figure 30 r. Yellow perch 1972.

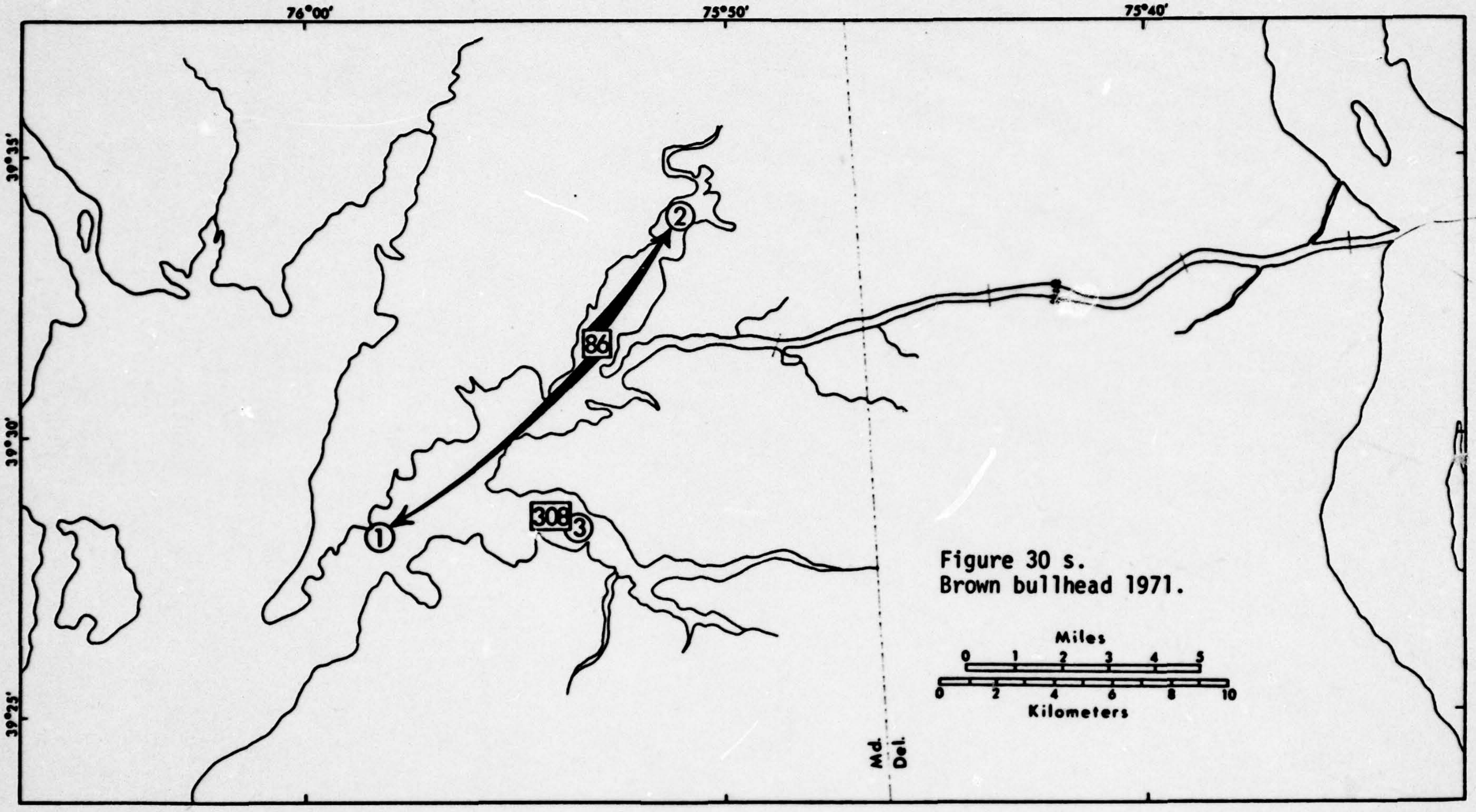


Figure 30 s.
Brown bullhead 1971.

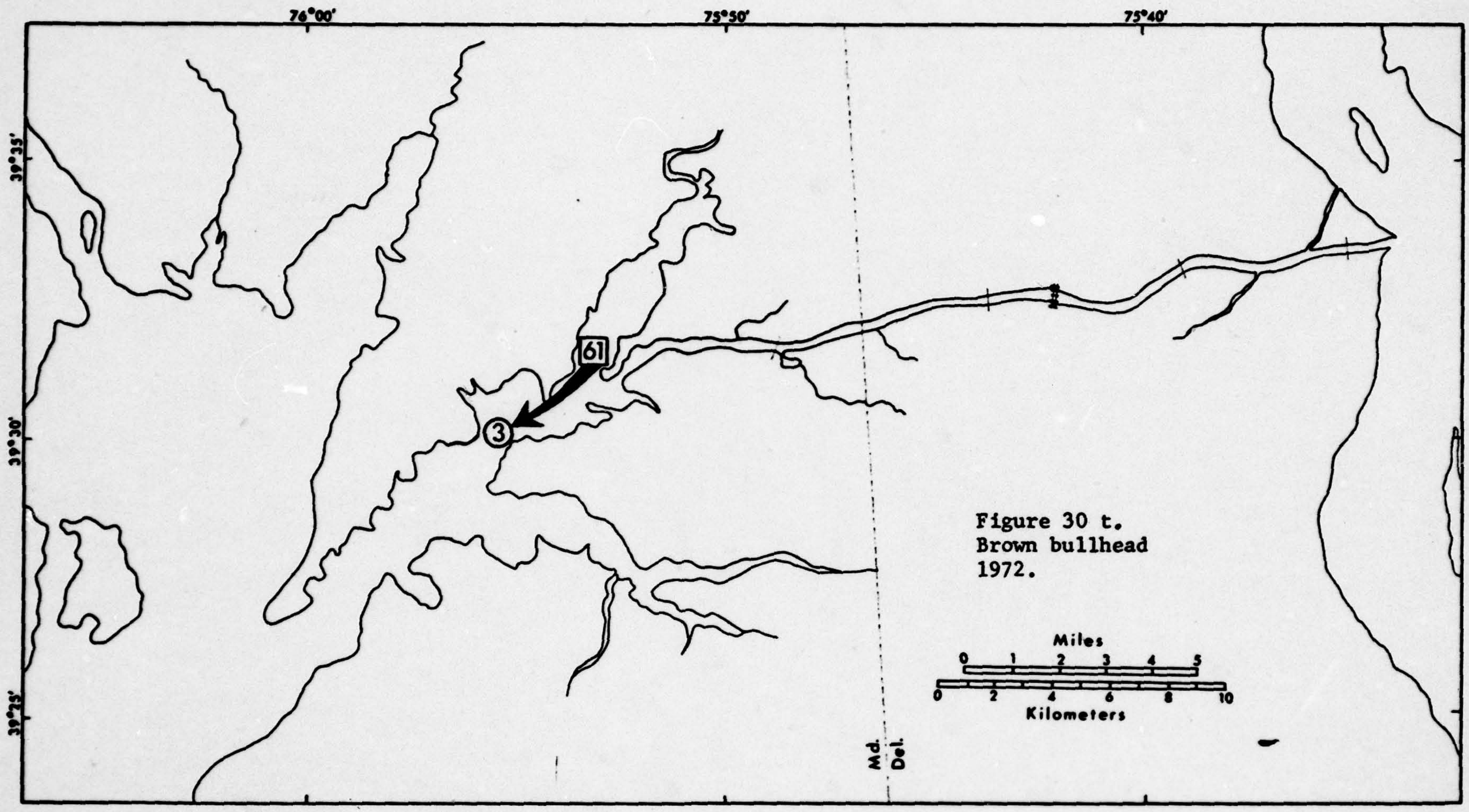


Figure 30 t.
Brown bullhead
1972.

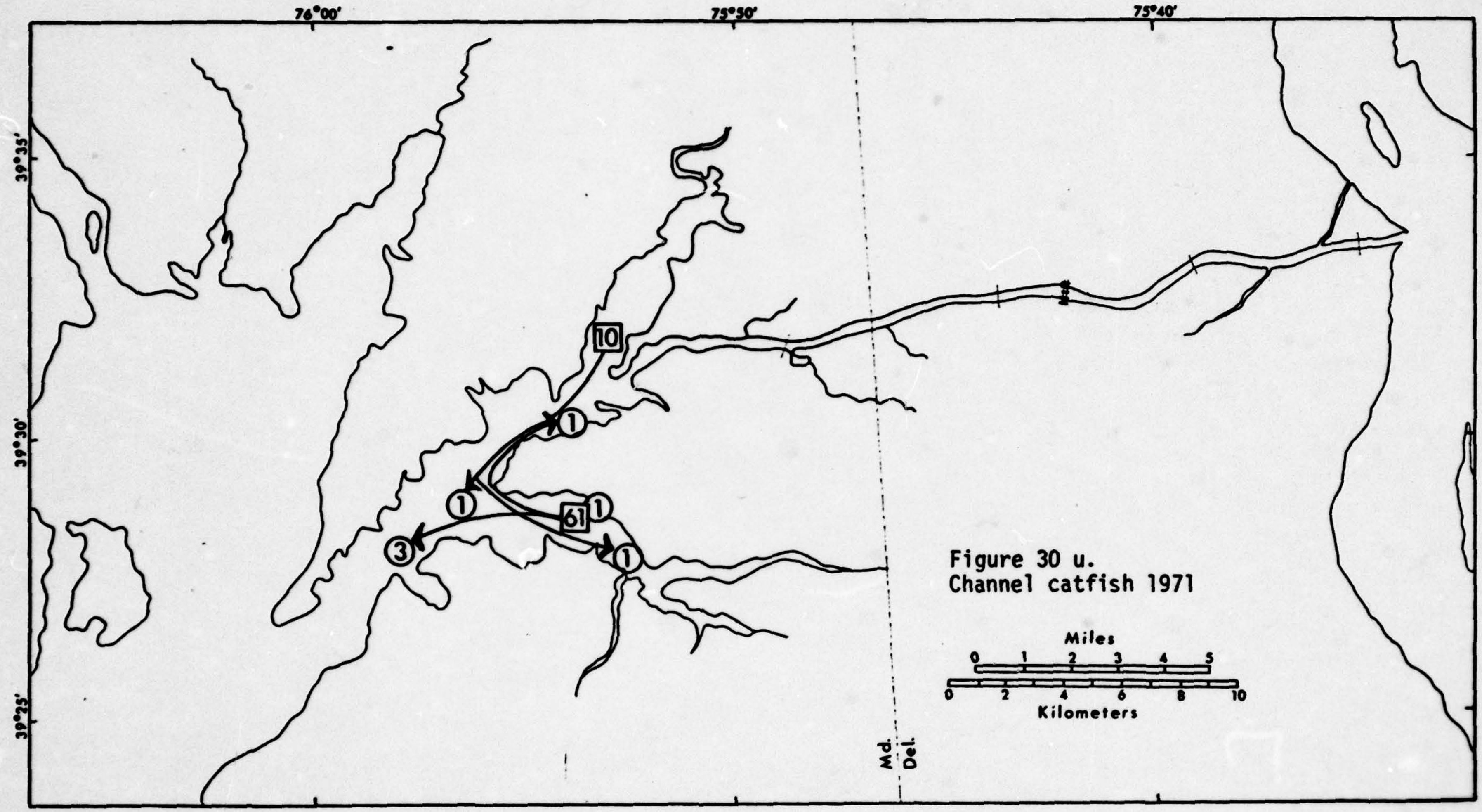


Figure 30 u.
Channel catfish 1971

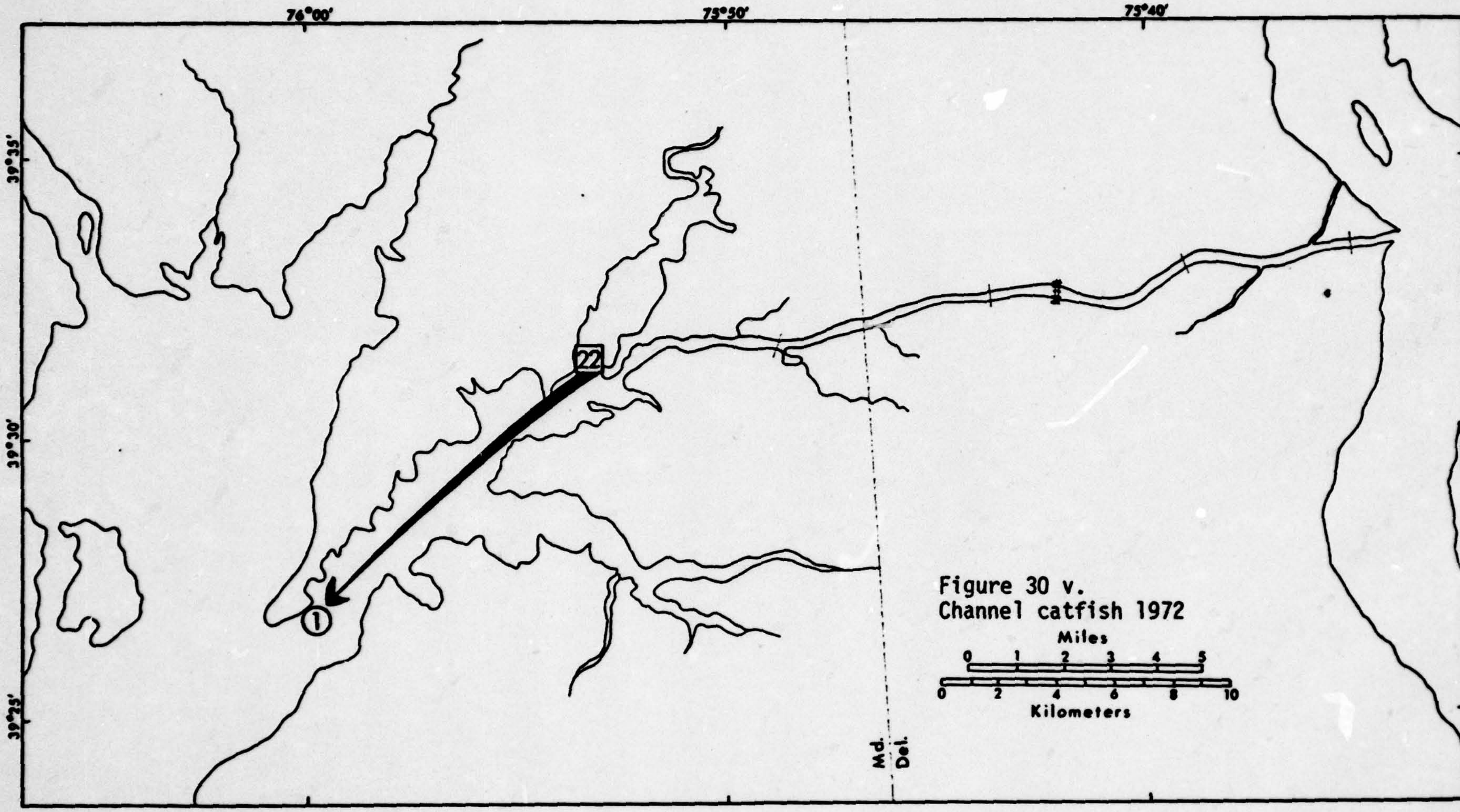


Figure 30 v.
Channel catfish 1972

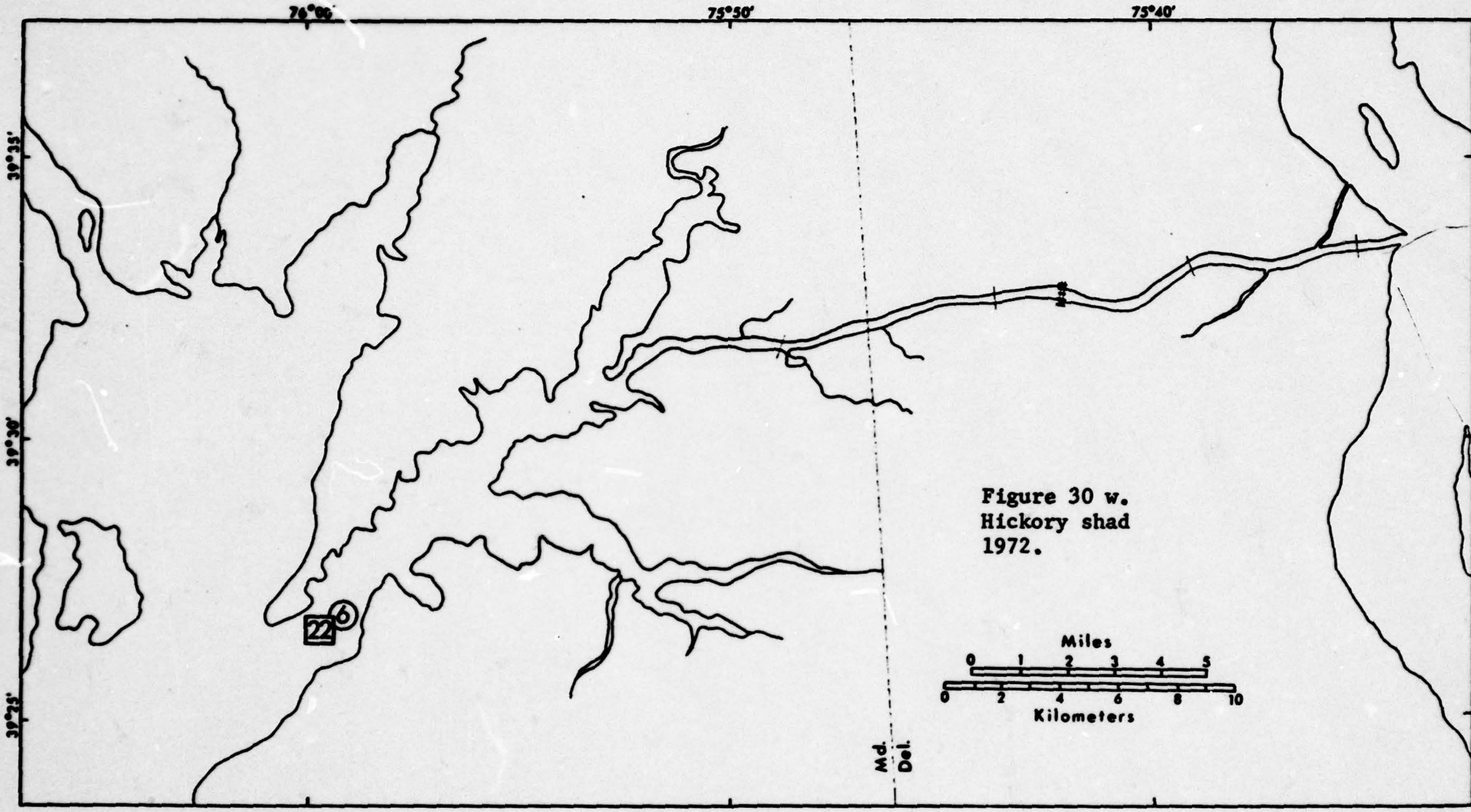


Figure 30 w.
Hickory shad
1972.

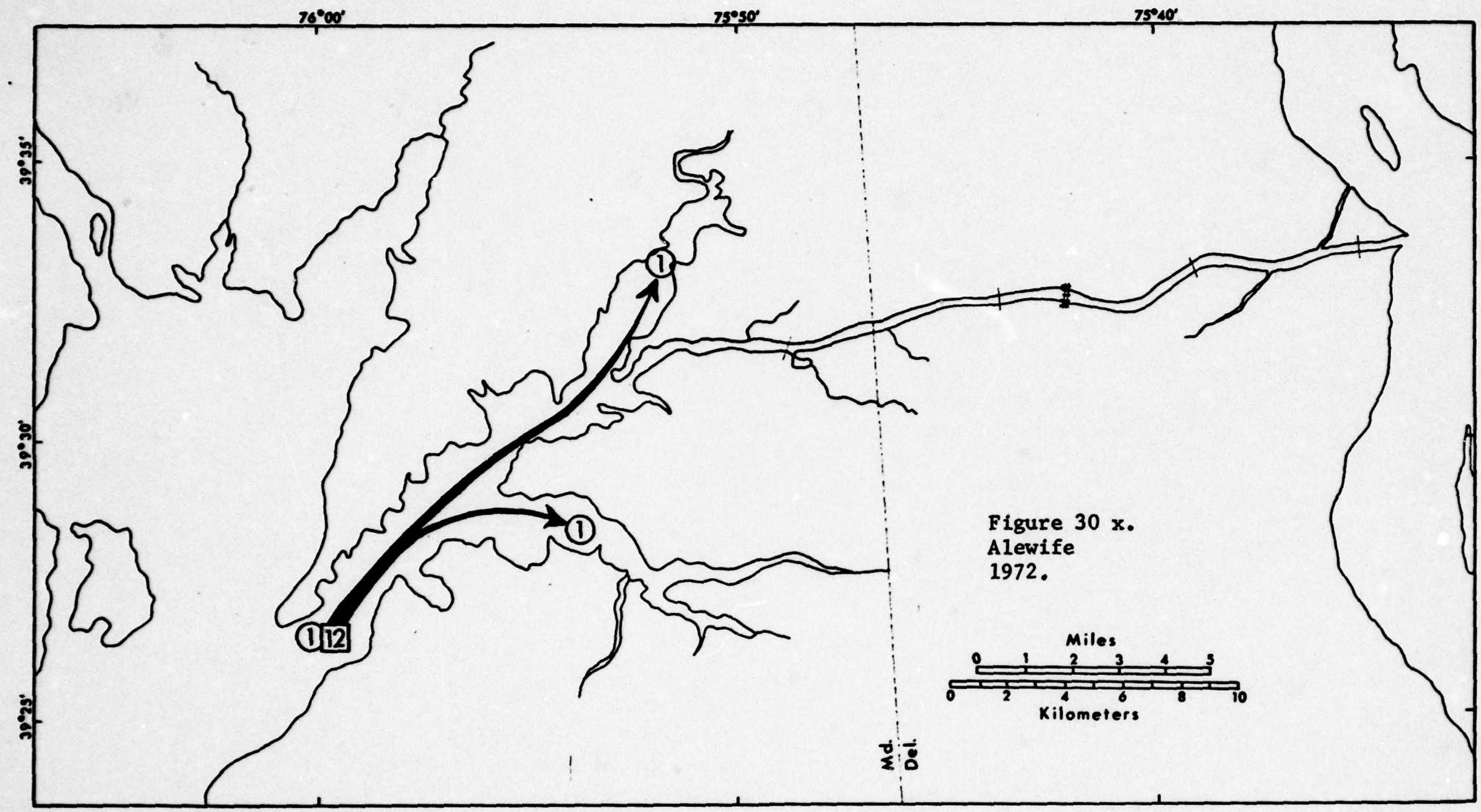


Figure 30 x.
Alewife
1972.

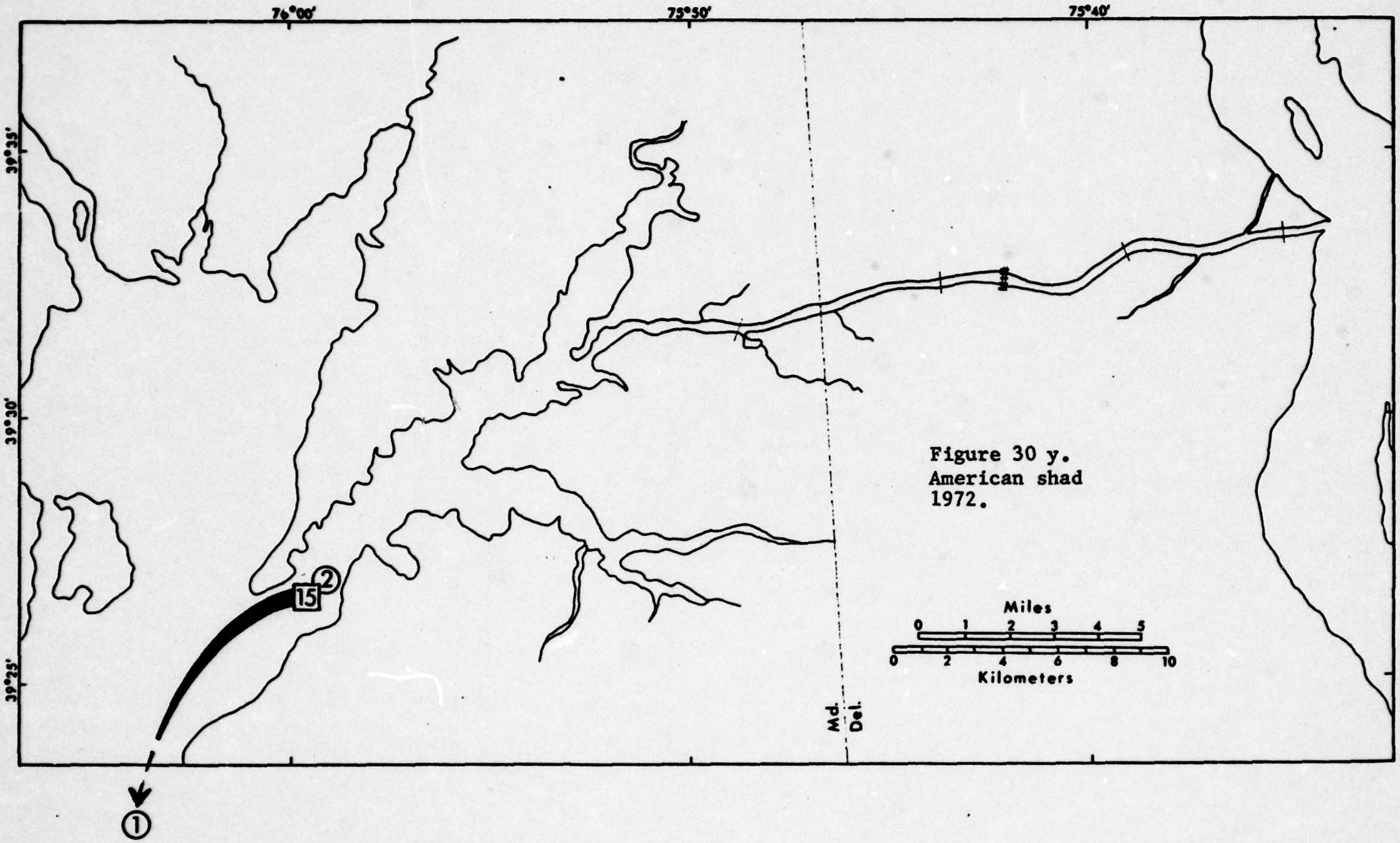


Figure 30 y.
American shad
1972.

APPENDIX VIII-B

Summary of Ultrasonic Tracking Program, Chesapeake and Delaware Canal Investigations

John S. Wilson

Natural Resources Institute

Chesapeake Biological Laboratory

University of Maryland

Center for Environmental and Estuarine Studies

Contract No. DACW-61-71-C-0062, Army Corps of Engineers, Philadelphia District

NRI Ref. No. 74-38

ABSTRACT

Several aspects of the design and use of ultrasonic transmitters are discussed.

During April and May of 1971 and 1972, 17 sexually mature striped bass, Morone saxatilis, were tagged with 74 kH_z or 130 kH_z ultrasonic tags and released in the Chesapeake and Delaware Canal area. In 1973, 4 American shad, Alosa sapidissima, were ultrasonically tracked in the Delaware River. Twelve striped bass and all the American shad were tracked continuously using portable listening gear. Seventeen-ft outboard boats were the primary, but not exclusive, tracking platforms and were satisfactory in sheltered waters. Maximum continuous track duration was 60 h. Six striped bass were to be tracked remotely by automatic shore monitors. The observed behavior of tracked fishes is noted.

Increased current velocities in the enlarged Canal are a nonsignificant deterrent to the movement of adult or sexually mature striped bass through the Chesapeake and Delaware area system. A working hypothesis of the movement of striped bass in the C and D Canal area is presented.

ACKNOWLEDGMENTS

Dr. Ted S. Y. Koo originated the concept of using ultrasonic tags in this study and enthusiastically encouraged and supported the electronics development pahse. His thoughtful direction of this program, including many hours spent in the field, is readily acknowledged and fully appreciated.

The success of the observational phase of such a study is heavily dependent upon the perception and perseverance of the individual members of the tracking teams. In this regard, I am greatly indebted to Melvin Beaven, Brooke Gray, Thomas Johnson, Charles Main, Terrance Peterson and Peter Zeni.

Many others participated in the field work, including John Cooper, John Cronin, Larry Dorsey, William Keefe, Robert Lippson, Robert Miller, Martin O'Berry, Michael Reusing, Douglas Ritchie, and Ruth Wilson. My appreciation is extended to all.

Design Considerations of Ultrasonic Transmitters as Fish Tags

The Ultrasonic Transmitter as a Fish Tag

Mark and recapture studies of fish movement are useful techniques of the fisheries biologist. Fishes have been marked by dyeing, tattooing, low and high temperature branding, fin-clipping, and by a variety of internal and external tags. Marked fishes are released and hopefully recaptured in order to provide information on such problems as population size, migration, behavior, homing and guidance cues, and rates of movement.

Conventional fish-tagging techniques enable fisheries biologists to obtain a large sample size at a relatively small effort per fish. Results are often dependent upon the cooperation of sport and commercial fishermen in recapturing the tagged fish and accurately reporting the circumstances of each recapture. A device which would allow the biologist to follow an individual fish and to chart its movements necessarily greatly reduces the sample size but yields precise information.

Miniaturized ultrasonic transmitters attached to free-swimming fishes can be used to provide instantaneous position data. The essential elements of such a system are the ultrasonic transmitter, on or in a fish, and a hydrophone receiver system used to determine the transmitter's presence and location. The electronic tag may be monitored either on a continuous basis by mounting the tracking equipment on rafts or boats and following the fish's movement or by placing automatic detection equipment at fixed positions to record the passage of tagged fishes.

Ultrasonic tagging is best suited for relatively short-term studies of the behavioral characteristics of aquatic animals as constrasted with lengthy conventional tagging programs. This is due to several factors:

1. The active life of the ultrasonic transmitter is limited by the capacity of its internal batteries.
2. Adverse weather and water conditions can interfere with or completely disrupt the tracking activities.
3. The technique is expensive. The quantity and quality of data generated is a direct function of the man-hours invested. Continuous monitoring is the most precise mode, but the most expensive in terms of personnel. Fixed-location automatic monitors demand less support time but provide lower quality information.

A well-designed ultrasonic fish tag should have a size, method of attachment, and transmitting frequency which does not alter the behavior of the host fish (nor the behavior of other animals toward the tagged fish). The transmitter must have sufficient range to permit easy tracking and to allow good separation of the tracking gear from the fish so that its presence does not alter behavior. The longevity of the tag must suit the study requirements.

In the design and utilization of ultrasonic transmitters, one must remember that the nature of the output is not electromagnetic radiation, such as utilized in radio, radar and light transmission, but rather is an acoustic or pressure wave of particle motion which cannot propagate across a vacuum. Transmitter design is greatly dependent on some aspects of sound propagation.

Acoustical energy is dissipated by three phenomena: spreading, absorption, and dispersion or scattering. Spreading losses are described by the familiar inverse square notation in which the energy level at some distant

point (with respect to the energy source level) is inversely proportional to the square of the separation distance.

Absorption losses are a function of temperature, dissolved solids and the frequency. Absorption losses increase with decreasing temperature and with increasing frequency and total dissolved solids, particularly $MgSO_4$. Scattering losses result from the deflection of acoustic energy by entrained particles, gas bubbles and biota. Spreading and scattering losses are for the most part not responsive to manipulation. This is also true of some aspects of absorption losses. Selection of the operating frequency, however, does provide some flexibility. Since absorption losses rise with increasing frequency, the designer looking for maximum range should select the lowest frequency consistent with other design requirements.

The relationship between the frequency and the physical size of some transmitter components precludes using very low frequencies. Additionally, the sound or its subharmonics must not be detectable by the fishes in the studied system. Since size and frequency relationships have kept operating frequencies in the region of 50 kH_z and above and fishes have poor to non-existent auditory capabilities above 2 kH_z, transmission detection by fishes is not a problem. This may not be true in studies of large marine mammals with higher auditory perception thresholds.

Transmitter range, in addition to its relation to frequency, is also a function of the operating life of the transmitter. At a given frequency, range can be extended by increasing the energy output. Since the small internal batteries, which power all ultrasonic transmitters reported to date, have a fixed limited capacity, usually rated in milliamperes per hour, increased energy output must be at the expense of operating time. In other

words, the battery may be exhausted at a high rate for a short time or at a lower rate for a longer period.

Batteries as power sources for ultrasonic tags are a major problem in transmitter design. They are bulky (often comprising more than 50% of the volume of a transmitter package), relatively inefficient and prone to premature, unpredictable failure. Unfortunately, there is little hope that alternative power sources will be practical for ultrasonic transmitters in the ear future.

Transmitters can be, and have, operated continuously; that is, made to produce an unmodulated ultrasonic signal, but this is wasteful of energy. Pulsing the output not only extends the transmitter operating life but creates the possibility of reporting more than location data. If the pulse repetition rate is made to vary as a function of temperature or pressure, the transmitter becomes a remote sensing thermometer or depth sensor. Ultrasonic physiologic telemetry has been conducted with large marine animals, and smaller transmitters now being developed will make similar studies of of fishes practical.

METHODS AND MATERIALS

The Ultrasonic Transmitter

The ultrasonic transmitters used in this study have similar characteristics although two different sources for the devices were utilized. The transmitters used in 1971 and in one instance in 1972 were Type SR-69B produced by Smith-Root Electronics of Seattle, Washington (see Fig. 1 and Table 1). With the exception noted, the transmitters used in 1972 were produced at the Chesapeake Biological Laboratory. In 1973, one commercial transmitter was used.

Both types of transmitters employ a transistor, squegged, Hartley oscillator whole pulse repetition rate may be varied in construction but is fixed in an an individual device when ready for field use. An additional audio stage, Q1, amplifies the pulsed oscillator output and drives a piezoelectric crystal which functions as a transducer and radiates the ultrasonic energy. The tag design does produce some unshielded radio frequency energy at the same frequency as the ultrasonic output but the range of this radiation is very limited under water and does not make a useful contribution to the range of the device.

The power is supplied by a series of 6 #575 mercury batteries connected in series. This configuration produces an initial output of 8.4 V, d.c., at 100 milliamperes (mA)/h or 0.1 A/h. In use, the voltage drops to 8.2 V and remains at this level for most of the transmitter operating life, until the individual cells begin to fail. The 100 mA/h is the current rating of one cell. The series configuration of the 6 cells increases the voltage output of the individual cells by a factor of 6 but does not make the current additive. Replacing the expended battery pack restores the transmitter to full operation.

The electronics are potted in an epoxy compound inside a plastic capsule, high impact polystyrene in the case of the commercial transmitter and in a thin wall polyallomer centrifuge tube for the tag which I constructed.

The longevity of all transmitters is a function of two factors: a) the current consumption during the conduction phase, when the transmitter is producing an output; and b) the duty cycle or the percent of 'on' time. The manufacturer's specifications call for a 2% duty cycle but both the commercial and non-commercial transmitters have duty cycles of 1% or less.

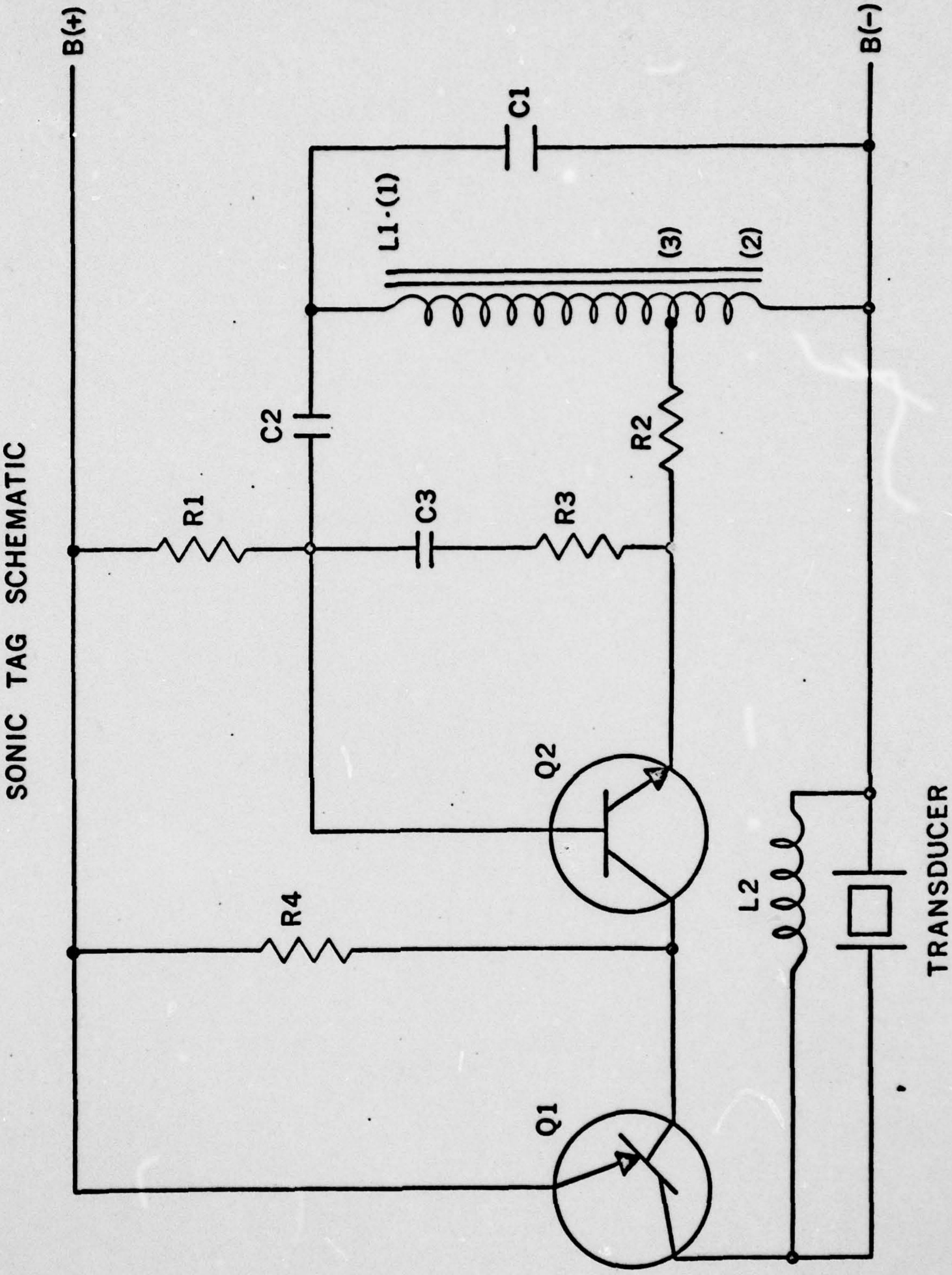
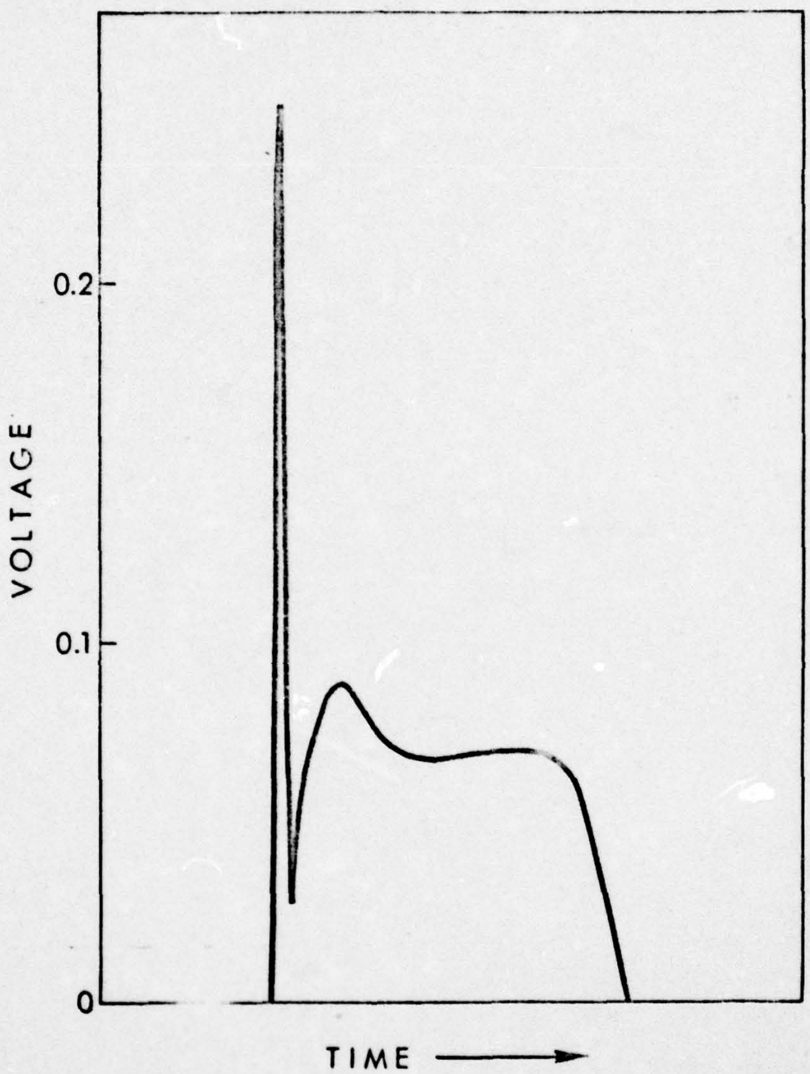

SONIC TAG SCHEMATIC
B(+)
B(-)
C1
L1·(1)
(3)
(2)
C2
R2
R1
C3
R3
Q2
R4
L2
TRANSDUCER
Q1

Figure 1.

Table 1. Component values for Smith-Root transmitter SR-69B.

C1	.0047 microfarad
C2	.470 picofarad
C3	1.0 microfarad
R1	2.5 meg ohms
R2	47 ohms
R3	varies part of RC. pulse rate determining network
R4	470 ohms
L1	345 turns tapped at 55 turns 1mH
L2	1 mH radio frequency choke
Q1	2N4291
Q2	2N4286
Transducer	PZT tube 0.5 x 0.5 inches
Battery	Mallory 303940 8.4 volts at 100 mA/H

[1] An operating mode characterized by periodic rather than continuous oscillation. A squegging oscillator produces a series of pulses.



CURRENT WAVEFORM

FIGURE 2

The transmitter consumes current only during the pulse phase, although the waveform across a one ohm sampling resistor, monitored to indicate current, is rather complex (see Fig. 2). An initial, very short-duration, spike is followed by a longer, lower-magnitude segment. The only current which flows during the interpulse period is the internal reverse biased leakage current of the transistors. The pulse repetition rate in a completed transmitter is not a significant factor in current consumption and thus the transmitter longevity. There is almost no difference in longevity between the most rapid and the slowest pulse repetition rate transmitters. This is due to the fact that the pulse length is not constant but varies inversely as the pulse repetition rate. In theory, assuming a duty cycle of 2% and a pulse repetition rate of 40 pulses/min or 0.67 pulses/sec, the pulse has length of 30 millisec 0.03 sec. For a pulse repetition rate of 480 pulses/min (8 pulses/sec), the pulse length is 2.5 msec (0.0025 sec). This is due to the nature of the squegging oscillator[1] and the relation of RC (resistor-capacitor) time constant which determines the squegging rate. Squegging rate is a direct function of the RC time constant. Since this constant is a multiplicative result of both resistance and capacitance, either parameter may be varied to change the pulse rep rate.

Table 2 displays the theoretical relationship of pulse rate and pulse length in a squegged oscillator. Figure 3 illustrates from actual measurements the relationship of pulse rep rate and duty cycle. Duty cycle may be seen to vary only slightly, and linearly with large changes in pulse repetition rate caused by varying R3, the resistance in the RC time constant network. Holding the value of R3 constant and varying C3, the capacitor in this same network produces similar results with even better agreement with theory.

Table 2.

Pulse rate vs. pulse length	2.0% duty cycle
Pulses/min	**Pulse length in msec**
40	30
80	15
160	7.5
240	5.0
360	3.3
480	2.5

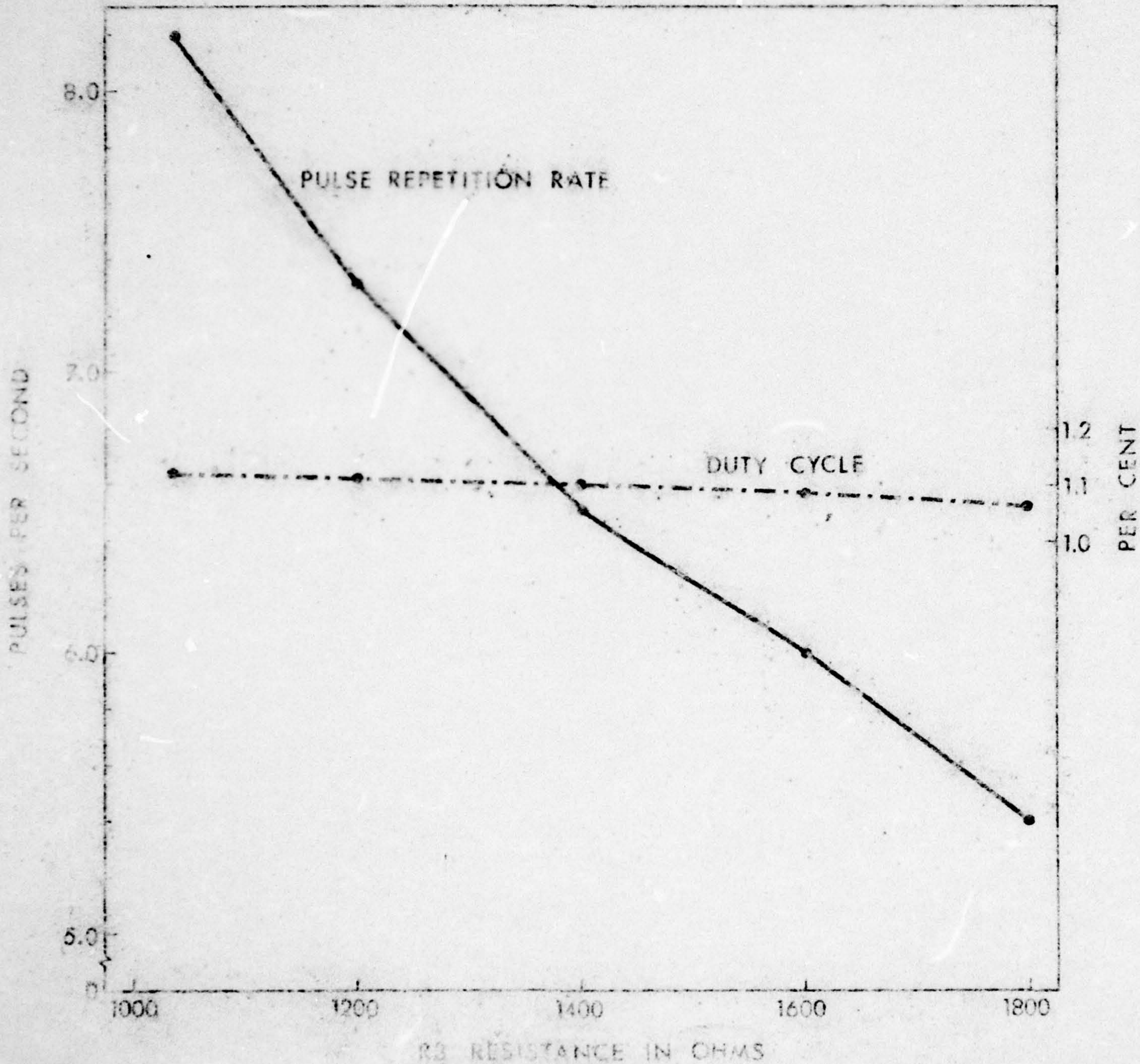

PULSE REPETITION RATE
DUTY CYCLE
PULSES PER SECOND
8.0
7.0
6.0
5.0
0
PER CENT
1.2
1.1
1.0
1000
1200
1400
1600
1800
R3 RESISTANCE IN OHMS

FIGURE 3

The fundamental or carrier frequency for most tracking missions was 74±1.5 kH_z of 74×10^3 cycles per second. The other frequency employed in the study was 130×10^3 cycles/sec. The 130 kH_z frequency was required for compatibility with the fixed-tuned 130 kH_z shore monitors, borrowed from California Fish and Game. The lower frequency, 74 kH_z, has an advantage in that given the same electrical power output from the transducer, the lower frequency suffers less attenuation over a given distance, i.e., has a greater range than the higher frequency transmitter. This range difference is due to fundamental physical laws governing the relative attenuation of varying radiation frequencies in water. Lower frequencies thus provide a 'free ride' by increasing range with no increase in current consumption.

A wide variation in the range of individual commercial transmitters has been noted. A small sample of commercial transmitters show that some units have a range of no more than 50% of other units. The variation in range is not specified by the manufacturer of the commercial transmitters. The variations in range of the laboratory-produced transmitters has been held to a much smaller value.

Section II. Ultrasonic tracking

AD-A073 697 MARYLAND UNIV SOLOMONS NATURAL RESOURCES INST F/G 8/8
HYDROGRAPHIC AND ECOLOGICAL EFFECTS OF ENLARGEMENT OF THE CHESA--ETC(U)
SEP 73 D E RITCHIE, T S KOO DACW61-71-C-0062

UNCLASSIFIED NRI-REF-74-42 NL

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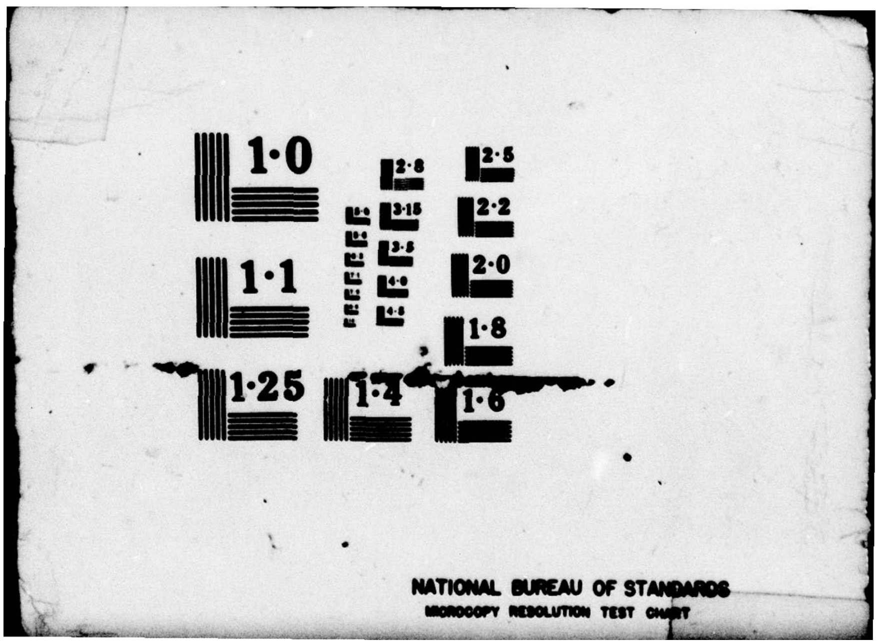

1.0
2.8
2.5
3.15
2.2
3.5
2.0
1.1
4.0
4.5
1.8
1.25
1.4
1.6
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Ultrasonic Tracking

The summary of ultrasonic tracking activities during the spring of 1971, when five adult striped bass, Morone saxatilis, (Fish Nos. 1 through 5) were monitored continuously, was presented in C and D Canal Investigations (Contract No. DACW-61-71-0062) Quarterly Status Report No. 3, and in Koo and Wilson (1972).

Between 19 April 1972 and 11 May 1972, a total of 12 striped bass were tagged with ultrasonic transmitters, released and tracked. Six of these fish (Nos. 7, 8, 9, 10, 12, 13) were tagged with 130 kH_z tags for detection by the two automatic shore monitors at Old Town Point Wharf and at Chesapeake City.

Six additional striped bass (Fish Nos. 6, 11, 14, 15, 16, 17) were tagged with 74 kH_z transmitters and were continuously tracked using portable monitors on small boats on a 24 h per day basis. Lengths of tracks varied from 2 h and 5 min to 59 h and 15 min. one fish, tagged with a 130 kH_z (shore monitor) tag, was also tracked on a continuous basis. Four ultrasonically tagged American shad, Alosa sapidissima, were tracked in the Delaware River estuary in early May of 1973.

The physical size of the ultrasonic transmitter used, 65 mm long by 14 mm diameter, precludes the tagging of small fishes. Striped bass (Morone saxatilis) were chosen for ultrasonic tagging on the basis of ecologic and commercial importance, size, and movement patterns. Striped bass were considered especially important because of their utilization of the study area as spawning grounds. Striped bass were recovered from the fishing gears in sufficiently good condition to warrant their use in this study.

Two types of equipment for tracking the tagged fish were employed in this study; mobile, manually-operated detection equipment mounted in boats and, in 1972, fixed location, automatic shore-based monitors.

The automatic shore monitors recorded a signal by means of a slow-speed magnetic tape whenever the submerged hydrophone sensed a signal of the proper frequency and amplitude. A time base signal was also recorded automatically so that events could be correlated to a real time base. Since this equipment responded to any signal of suitable frequency and amplitude such as passing ship traffic, it was necessary to learn to discriminate between the tag-produced signal and other cyclic sounds.

Six automatic shore monitors were borrowed from California Fish and Game Commission. Two monitors and hydrophones were determined to have sufficient sensitivity to warrant their installation along the Canal. One unit was installed at Town Point Wharf and the second unit was placed in front of the Corps of Engineers' administrative headquarters building at Chesapeake City. Had more functioning monitors been available, they would have been deployed to cover the entire Canal area from Turkey Point to Reedy Point.

Striped bass, fitted with 130 kH_z, shore monitor compatible tags, were released on two dates within the spawning period. It was soon determined that the hopper dredge, "Comber", operating in the Town Point Wharf area, produced sufficient acoustical noise so as to render that station useless. Data from the single remaining station are much reduced in value and this type of tracking was terminated.

The primary method of locating ultrasonically tagged fish involved the use of receivers aboard boats which followed the fishes' movement on a continuous basis. In spring of 1971, tracking was accomplished

using the R/V ORION, as well as outboard-powered 17-ft boats. In 1972 and 1973, the open boats were used exclusively. In 1972, a four-man tracking team was split into two crews of two men each. Tracking crews rotated on an eight-h-on and eight-h-off duty schedule. Personnel were rotated on station by means of a second boat so that the tagged fish was under surveillance at all times. In these open boats, the tracking gear was set up so that one man could track the fish and run the boat.

The tracking boats were equipped with VHF radiotelephones and, in the middle of May 1972, with an indicating fathometer.

Fishes used in this study were acquired from commercial fishermen using two types of gear; stake gillnets deployed 24 h per day in non-channel areas of the lower Elk River and drift gillnets fished between Welch Point and Summit Bridge during periods of slack water.

Individual fish to be ultrasonically tagged and tracked were selected on the basis of species, size, condition, sex, and stage of sexual maturity. An additional factor, availability, became a consideration in early May 1972 and 1973, when the number of large fish decreased markedly.

Fishes were retrieved from the nets, measured, weighed, tagged with an external Peterson tag and an internal ultrasonic transmitter. The ultrasonic tag was introduced via a tube inserted past the pharyngeal teeth, through the esophagus, and into the stomach. In striped bass, the stomach forms a blind pouch and placing the tag in this caecum reduces the probability that the device would be passed through the intestine. The use of the tube both reduced the time required for tag insertion and ensured that the pharyngeal teeth did not abrade the watertight tag capsule.

The internal tagging site was chosen after tests conducted by Dr. Andy McErlean and Mr. Larry Dorsey at the Hallowing Point Field Station indicated that striped bass retained similar size dummy tags without irritation of the stomach lining. During field use in 17 fish, only 1 regurgitation was noted. This was after a continuous track over 58 h. During our longest track, 1 fish was followed intermittently for 99 h. Other species react differently to internal tag placement. In tests of 4 channel catfish and 1 white catfish, all tags inserted into the stomach were regurgitated within 24 h. Sixty percent were rejected in a few minutes.

Tagged fish were released at the capture location and were not transported in 1972 and 1973 and, with one exception, in 1971. The time out of water was no more than 1½ min, usually under 1 min. Fish were measured and tagged while being retained in a large rectangular fiberglas tub. After tagging, fish were not held in a holding tank or otherwise confined but, instead, were immediately released. It was reasoned that if the animals were in good condition before tagging, the 90 sec or less spent out of water was not sufficiently detrimental to be lethal. It was further assumed that holding the fish for extendedlengths of time in a necessarily small tank or live box would add to the fish's disorientation and would extend the period of atypical behavior.

The tracking crew activated the detection equipment prior to the release of the tagged fish and its movements were followed as soon as it was released. Tagged fish were tracked until one of the following criteria had been met:

1. Fish left the study area.
2. Tagged fish regurgitated the ultrasonic transmitter.
3. Insufficient visibility to accurately establish the tracking boat's position (a problem only on open-water portions of the study area).
4. Loss of signal from the transmitter in the fish.
5. Unsafe small-boat weather.

Table 3 presents a summary of the tracking activities in 1971 and 1972. In this table, track no. refers to the year and sequence of the track. Fish No. is an identification number from a continuous series throughout 1971 and 1972. Date rel. is the date of release. Rel. loc. is the release location. Gear is either SG (stake gillnet), or DG (drift gillnet). Pet. tag is the i.d. number of the Peterson disc tag and U/S tag no. is the serial number of the ultrasonic tag. Freq. refers to the operating frequency of the ultrasonic transmitter. Mat. indicates the sexual maturity of the gonads, immature, mature or refractory; and con. refers to the spawning condition -- pre-spawning, running ripe, or spent. Last known pos. is the location of the last ultrasonic contact.

Table 3

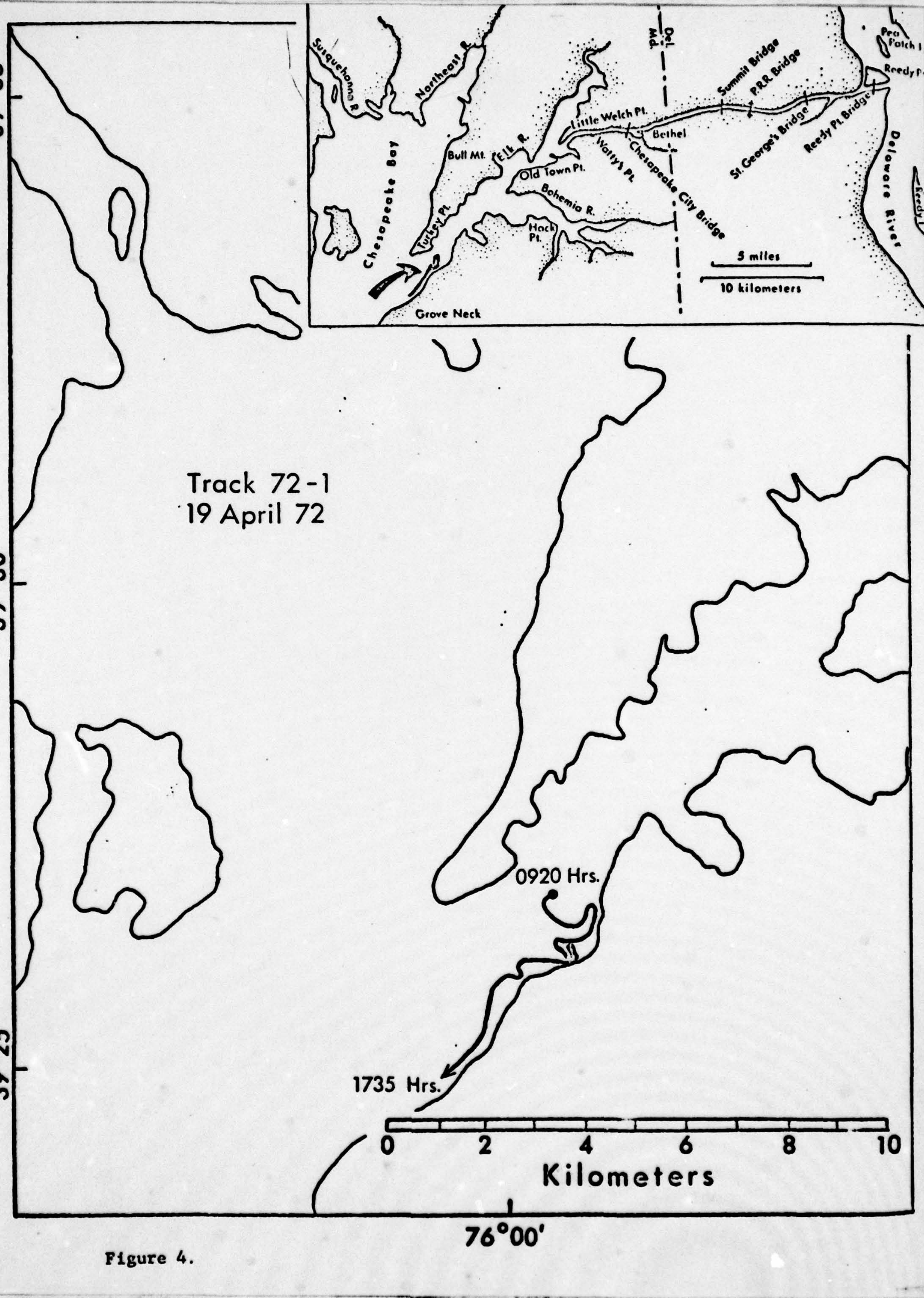
Track No.	Fish No.	Date rel.	Rel. loc.	Lat. & Long.	Gear	Pet. tag no.	U/S tag no.	Freq. (kHz)	Fish length (mm)	Sex	Mat.	Con.	Total Track Time (hr.min.)	Total Track dist. (km)	Last known pos.	Lat. & Long.
						1971										
71-1	1	4-19-71	Ches.City C&D C.	39°31'45"N 75°48'48"W	S.G. net	---	002	74	470	M	Mat.	Pre S.	16:20	16	Bohemia R.	39°29'00"N 75°55'15"W
71-2	2	4-20-71	Bethel Md/Del line	39°32'08"N 75°46'49"W	D.G. net	BB610	008	74	908	F	"	"	11:13	21.4	Del.R. Reedy Is.	39°32'53"N 75°32'37"W
71-3	3	4-21-71	"	"	"	BB609	005	74	525	M	"	Running ripe	8:20	16	C&D C. Reedy Pt. Bridge	39°33'35"N 75°35'04"W
71-4	4	5-3-71	Elk R. Turkey Pt.	39°26'55"N 76°00'05"W	S.G. net	CC314	007	74	825	F	"	Post S.	4:22	12	Elk R. Old Town Pt. Wharf	39°30'20"N 75°54'40"W
71-5	5	5-17-71	1 mi. E of RR Br.	39°32'33"N 75°42'15"W	D.G. net	CC388	006	74	790	F	"	"	91:35	6.5	C&D C. Joy Run	39°32'28"N 75°41'28"W

Table 3

Track No.	Fish No.	Date rel.	Rel. loc.	Lat. & Long.	Gear	Pet. tag no.	U/S tag no.	Freq. (kH_z)	Fish length (mm)	Sex	Mat.	Con.	Total track time (hr.-min.)	Total track dist. (km)	Last known pos.	Lat. & Long.
						1972										
72-1	6	4-19-72	Crystal Beach Elk R.	39°26'50"N 75°59'22"W	S.G. net	CC371	308	74	692	M	Mat.	Pre S.	8:14	88	Pond Crk. Elk R.	39°25' 0"N 76° 0'38"W
	7	"	"	"	"	CC311	1006	130	735	M	"	"				
	8	"	"	"	"	CC301	1009	130	520	M	"	"				
	9	"	"	"	"	CC341	1005	130	825	Undetermined						
	10	"	"	"	"	CC375	1003	130	495	M	Mat.	Pre S.				
72-2	11	4-20-72	"	39°26'43"N 75°59'24"W	"	CC361	120	74	870	M	"	"	1:50	2.1	Elk R.	39°26'32"N 75°59'58"W
72-3	12	4-26-72	C&D C. Bethel	39°32'52"N 75°46'22"W	D.G. net	CC100	1015	130	794	F	"	"	60		C&D C. St. Georges	39°32'52"N 75°39'22"W
	13	"	"	"	"	CC101	1014	130	854	M	"	"			"	"
	14	"	"	39°32'10"N 75°46'10"W	"	CC102	312	74	927	F	"	"	59:46	11	Railroad Cut C&D C.	39°24'38"N 75°43'05"W
72-4	15	5-10-72	C&D C. Welch Pt.	39°31'23"N 75°52'29"W	"	CC103	320	74	465	M	"	Post S.	3:30	3	Elk R. Port Herman	39°30'18"N 75°54'21"W
	16	5-10-72	C&D C. Welch Pt.	39°31'23"N 75°52'29"W	"	CC104	311	74	730	F	"	"	37:10	18.1	Ches.Bay Turkey Pt.	39°26'15"N 76°01'05"W
	17	5-10-72	C&D C. Sandy Pt.	39°31'40"N 75°52'05"W	"	CC105	315	74	670	M	"	"	10:42	4.6	Elk R. Hylands Pt.	39°29'52"N 75°55'48"W

Description and Comments on Individual

Tracks in 1972 and 1973



Susquehanna R.
Northeast R.
Del. Md.
Summit Bridge
P.R.R. Bridge
Pea Patch I.
Reedy Pt.
Little Welch Pt.
Bethel
Chesapeake Bay
Bull Mt.
Elk R.
Old Town Pt.
Wattys Pt.
Chesapeake City Bridge
St. George's Bridge
Reedy Pt. Bridge
Delaware River
Bohemia R.
Turkey Pt.
Hack Pt.
5 miles
10 kilometers
Grove Neck
39°35′
39°30′
39°25′
Track 72-1
19 April 72
0920 Hrs.
1735 Hrs.
0
2
4
6
8
10
Kilometers
76°00′

Figure 4.

Track No. 72-1 Fish No. 6

Date tagged and released 19 April 1972 Time of release 0921

Length 692 mm Weight

Sex Male Maturity and condition Mature, running ripe

Ultrasonic tag S/N 308 74 kH_z

Peterson tag CC 371

Capture gear Stake gill net

Capture/release location Elk River near Crystal Beach, south side of ship channel 39^o 26' 50"N
75^o 59' 22"W

Last known position Elk River near Pond Creek mouth
39^o 25' 0"N
76^o 0' 38"W

Distance covered by fish during track 8780 meters

Track duration 8 h 14 min Average speed over the bottom 0.3 m/sec

Weather light S.W. winds
sunny with haze
air temp cool

General description of fish's movements.

This fish displayed an alternately moving and stopped pattern of movement with an average speed over the bottom of 0.3 m/sec. After being captured, tagged, and released in 6-7 m deep water, it moved toward the south bank of the Elk River and shallower water depth (1 m). The fish changed direction frequently but the overall pattern was movement toward the southwest out of the Elk River toward the Chesapeake Bay.

Unusual movement patterns noted.

Immediately after release, the fish was on the down-current side of the stake gillnet and was observed by the changing position of its UST signal to move laterally along the net face. This observation was confirmed by the crew of the second tracking boat. After at least 7 min of movement along the net face, the fish passed beyond the shoreward end of the net.

Track No. 72-2 Fish No. 11

Species - Striped bass

Date tagged and released 20 April 1972 Time of release 0830

Length 870 mm

Sex Male Maturity and condition Mature, running ripe

Ultrasonic tag S/N 120 74 kH_z Commercial manufacture

Peterson tag CC361

Capture gear Stake gill net

Capture/release location Elk River near Crystal Beach, south side of ship channel, 39°26'43"N 75°59'24"W

Last known position Elk River 250 meters west of release point 39°26'32"N 75°59'58"W

Distance covered by fish during track 2100 meters

Track duration 1 h 50 min Average speed over the bottom 0.32 m/sec

Weather Winds light from the southwest initially
Overcast, intermittent light rain
late in the track
Wind velocity increased during track
Air temperature cool

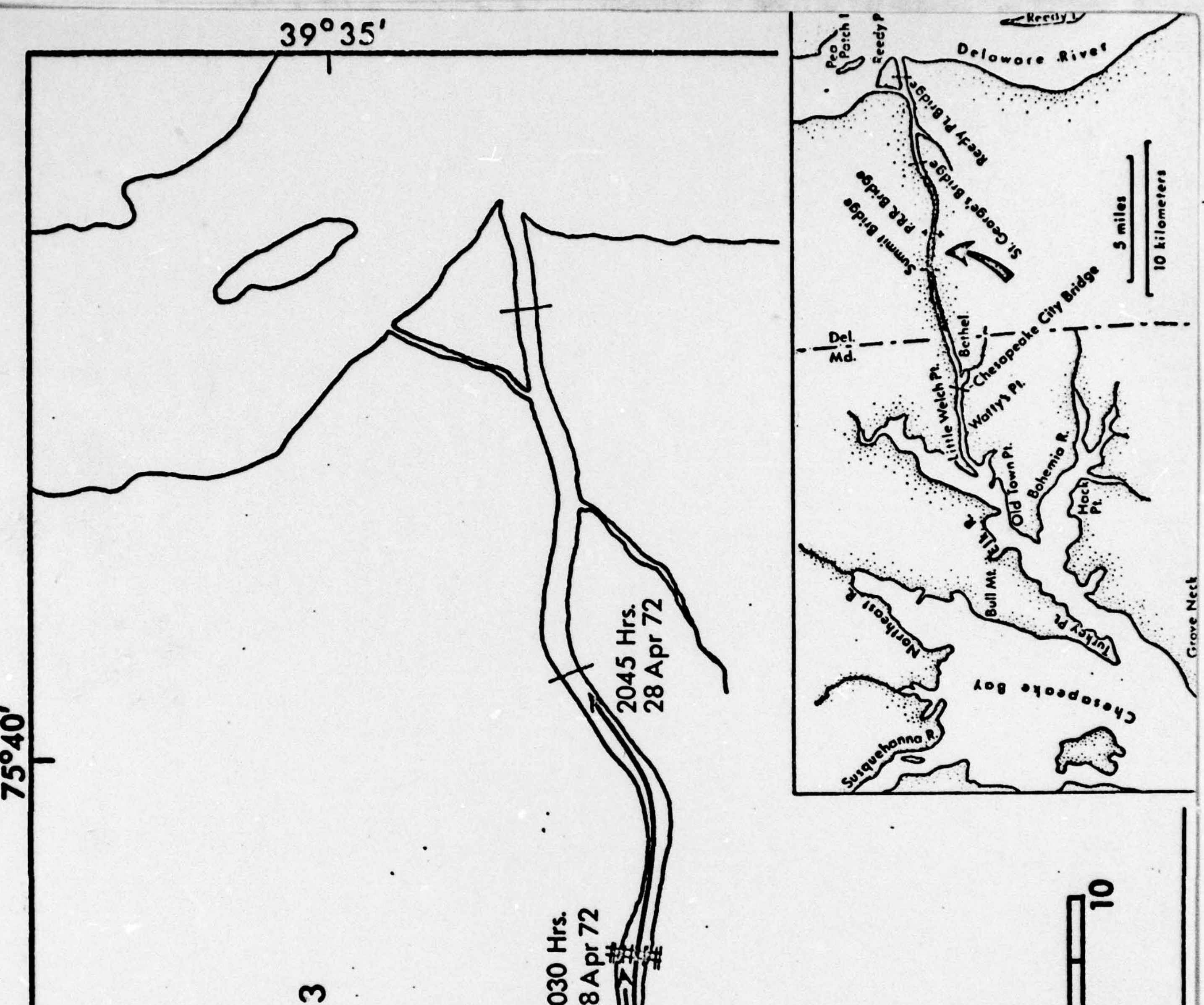
72-2 (1)

General description of fish's movements.

Fish #7 remained near the edge or in the ship channel in water depth varied from 6 to 12 m for the duration of the track. The fish moved sporadically for a large portion of the track. Its general direction became SW against an eastward flow in the later portion of the track. The fish was headed southwest toward the mouth of, and out of, the Elk River when the signal was lost.

Unusual movement patterns noted

This fish remained stationary at the face of a stake gill net. It did not move laterally along the net face, and was believed to be entrapped in the net. The fish moved away as the commercial fisherman raised the net and the two tracking crews then surmised that the fish may have been holding position at the net face but not entangled in the mesh.



39°35'
75°40'
Track 72-3
2045 Hrs.
28 Apr 72
2030 Hrs.
28 Apr 72
0905 Hrs.
26 Apr 72
0930 Hrs.
26 Apr 72
0
2
4
6
8
10
Kilometers
Delaware River
Reedy Pt. Bridge
St. Georges Bridge
Summit Bridge
P.R.R. Bridge
Chesapeake City Bridge
Bethel
Del.
Md.
Little Welch Pt.
Welty's Pt.
Old Town Pt.
Bohemia R.
Hack Pt.
Bull Mt.
Turkey Pt.
Northeast R.
Susquehanna R.
Chesapeake Bay
Grove Neck
5 miles
10 kilometers

Figure 6.

Track No. 72-3 Fish No. 12

Species Striped bass

Date tagged and released 26 April 72 Time of release 0930

Length 794 mm

Sex Female Maturity and condition mature/prespawn

Ultrasonic tag S/N 1015 130 kH_z

Peterson tag CC100

Capture gear drift gill net

Capture/release location Chesapeake and Delaware Canal, 910 m east of Maryland border
39°32'52"N
75°46'22"W

Last known position 39°32'52"N
75°39'22"W

Track duration 60 h

Weather Winds, light and variable to calm;clear sky.

Air temperature cool (8 - 10°C maximum, 2°C minimum)

Track No. 72-3 Fish No. 14

Species Striped bass

Date tagged and released 26 April 1972 Time of release 0939

Length 927 mm

Sex Female Maturity and condition mature - prespawning

Ultrasonic tag S/N 312 74 kH_z non-commercial

Peterson tag CC102

Capture gear drift gill net

Capture/release location released 910 m east of Md. border in the C & D Canal 39°32'10"N 75°46'10"W

Last known position 39°32'38"N 75°43'05"W off the mouth of the railroad cut in the C & D Canal

Distance covered by fish during track 11 km

Track duration 59 hours, 46 min Av. speed over the bottom 0.3 m/sec and 0.03 m/sec*

Weather Winds light and variable to calm; clear sky

Air temperature Cool (8 - 10°C maximum, 2° minimum)

* See track description and comments.

No. 72-3

General description of the fishes movements

Fish No. 14 was captured in a drift gill net in the Chesapeake and Delaware Canal near Bethel, Maryland. It was released into a slack current in the company of two other large, ultrasonically tagged striped bass. Fish No. 12 was a 794 mm pre-spawned female and fish No. 13 an 854 mm pre-spawned male. Fishes 12 and 13 were tagged with 130 kH_z UST for reception by the automatic shore monitors but their tag signals were detectable with the tunable receiver on the tracking boat.

Fish No. 14 swam near the north bank of the canal in an eastward direction, stopped for over an hour at the shadow of the summit bridge, and then resumed swimming east near the north bank of the canal until it reached the vicinity of the blind channel known as the railroad cut, where it stopped. This fish remained within a section of the canal 700 m in length from Wednesday afternoon until after dark on Friday evening.

Sometime after 2025 hrs on Friday, 28 April, the UST signal stopped changing location. The fish could have regurgitated or passed the transmitter and/or the fish could have expired and become lodged in the rocks that form a protective rip-rap along the canal bank. Regurgitation or passing the transmitter is more likely the explanation.

During the track of fish No. 14, the tracking crews also listened for a 130 kH_z tagged fish. Fish No. 12, a female, tagged and released within a few minutes of fish No. 14, was observed in the vicinity of the primary fish (Fish No. 14) until she reached the shadow of the Summit Bridge. Fish No. 14 stopped at the bridge shadow for over one hour, while fish No. 12 continued on without any apparent hesitation. The position of this 130 kH_z (fish No. 12) tagged, fish was not as closely monitored as was the 74 kH_z fish (No. 14), but the presence of the other

female was noted in close proximity to fish No. 14 for several long periods of time during the tracking period.

Unusual movement patterns noted.

Fish No. 14 exhibited three distinct movement patterns. Initially, she moved rather rapidly to the east for 5.7 km with an average speed over the bottom of 0. m/sec. This mean speed included the one h plus station holding at the shadow of the Summit Bridge. The speed over the bottom increases to 0.3 m/sec exclusive of this period. The station holding in mid-channel at the edge of the bridge shadow is the second type of movement pattern.

The third type of movement pattern occurred after fish No. 14 reached the vicinity of the railroad bridge. She localized her movements between the railroad cut and the overhead pipeline and remained in this area for the next 53 h. During this time she covered a ground distance of 5.3 km at a mean speed of 0.03 m/sec, an order of magnitude reduction. A significant factor in this reduced speed was many long periods when the fish remained near the bank at a fixed location.

It is possible that fish No. 14 spawned while being observed by ultrasonic tracking methods. This belief is based upon several considerations. When tagged and released, the fish was pre-spawned by sexually mature. It was captured in the company of other similarly sexual mature male and female striped bass.

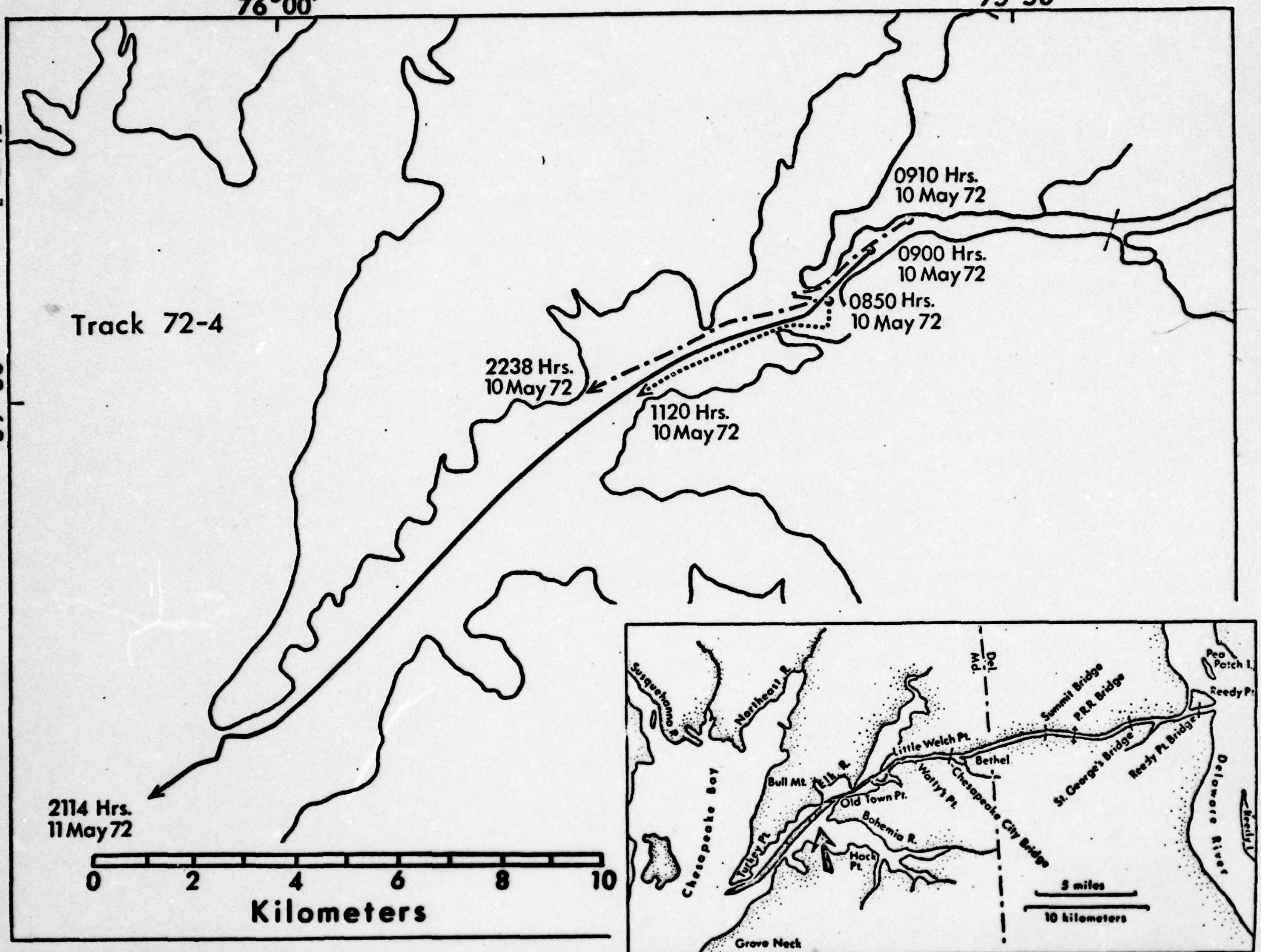
As observed by ultrasonic tracking methods, pre-spawned striped bass in good physical condition have characteristically moved rapidly, while post-spawned fish have exhibited long periods of no location change interspersed with slow movements. This fish first moved rapidly and directly and then its behavior changed abruptly to long periods of fixed position and very slow movements within a relatively small area.

Numerous instances of striped bass spawning activity were noted in the immediate vicinity of this fish's position while under observation. Photographs of some of these surface activities offer additional evidence that the species involved was striped bass. Analysis of fish egg collections made as part of the overall study demonstrate that the peak of spawning activity for striped bass in the C and D Canal occurred during the tracking period. These same collections also indicate that signifcant striped bass spawning takes place in the vicinity of this fish's location.

Comments on 72-3

A great deal of fish splashing on the surface were observed as a common event during the track of fish No. 14. The splashing was readily observed or heard at night when wind noise and other sounds were reduced but the activity was noted during the hours of daylight.

At least some of this surface splashing is presumed to have been striped bass spawning activity. Tracking crews saw large striped bass roll on their backs and swim in an inverted position on the surface for several seconds while accompanied by smaller fish splashing. These observations conform to the classic description of rock fights or striped bass nuptial dances in which a large female is observed at the surface surrounded by numerous smaller male striped bass.



76°00'
75°50'
39°30'
Track 72-4
0910 Hrs.
10 May 72
0900 Hrs.
10 May 72
0850 Hrs.
10 May 72
2238 Hrs.
10 May 72
1120 Hrs.
10 May 72
2114 Hrs.
11 May 72
0 2 4 6 8 10
Kilometers
Susquehanna R.
Northeast R.
Chesapeake Bay
Bull Mt.
Elk R.
Turkey Pt.
Old Town Pt.
Bohemia R.
Hack Pt.
Grove Neck
Little Welch Pt.
Welty's Pt.
Bethel
Chesapeake City Bridge
Del.
Md.
Summit Bridge
P.R.R. Bridge
St. George's Bridge
Reedy Pt. Bridge
Reedy Pt.
Pea Patch I.
Reedy I.
Delaware River
5 miles
10 kilometers

Figure 7.

Track No. 72-4 Fish No. 15

Date tagged and released 10 May 1972 Time of release 0850

Length 465 mm Weight 1.3 kg

Sex Male Maturity and condition Mature, post-spawning

Ultrasonic tag S/N 320 74 kH2 30 pulses/min

Peterson tag CC 103

Capture gear Drift gill net

Capture/release location 39°31'23" N 75°52'29" W
in the C & D Canal channel near Welsh Point

Last known position 39°30'18" N 75°54'21" W
off Port Herman

Distance covered by fish during track 3660 m

Track duration 3 h 30 min Average speed over the bottom 0.29 m/sec

Weather Wings breezy; fair sky

Air temperature cool

Track No. 72-4 Fish No. 16

Date tagged and released 10 May 1972 Time of release 0900

Length 730 mm Weight 5.9 kg

Sex Female Maturity and condition Mature, post-spawning

Ultrasonic tag S/N 311 74 kHz 192 pulses/min

Peterson tag CC 104

Capture gear Drift gill net

Capture/release location 39°31'31" N 75°52'17" W, in the C & D Canal channel near Welsh Point

Last known position 39°26'15" N 76°01'5" W, in the Chesapeake Bay southwest of Turkey Point

Track duration 37 h 10 min Average speed over the bottom .045 m/sec (5 Km in 31 h)

0.59 m (13.1 Km in 6 h, 10 min)

Distance covered by fish during track 18.1 km

Weather Winds breezy; fair sky

Air temperature cool

Track No. 72-4 Fish No. 17

Date tagged and released 10 May 1972 Time of release 0910

Length 670 mm Weight 3.6 kg

Sex Male Maturity and contition Mature, post-spawned

Ultrasonic tag S/N 315 74 kH_2 78 pulses/min

Peterson tag CC 105

Capture gear Drift gill net

Capture/release location 39°31'40" N 75°52'02" W
in ship channel near Welsh Point

Last known position 39°30'55" N 75°53'57" W

Distance covered by fish during track 4600 m

Track duration 10 h 42 min Average speed over the bottom
0.1 m/sec

Weather Winds breezy; fair sky

Air temperature cool

General description of fish's movements.

Albert (Fish No. 15), a 46 cm post-spawning male striped bass, moved rather deliberately from the release site on the south side of the navigation channel inside of Welch Point toward the mouth of the Elk River. Its last noted position was near Town Point after traveling over the bottom at a mean speed of 0.3 m/sec. Betty (Fish No. 16) a 73 cm post-spawning female striped bass, exhibited two rates of movement. For the initial 31 h of the track, Betty moved very slowly over a distance of 5 km with a mean speed over the bottom of 0.045 m/sec. At approximately 1645 on the second day of the track, this fish began heading west against the eastward flowing current. In the next 6 h and 10 min, Betty covered a distance of 13.1 km at a mean speed of 0.6 m/sec. The tracking crew terminated the track in open water when they could no longer establish their position with enough accuracy to make pursuit meaningful.

Charley (Fish No. 17), a 67 cm post-spawning male striped bass, moved from the release area near Sandy Point in Back Creek towards Welch Point. It remained in shallow water off the end of Welch Point for most of the 10th of May, the first day of the track. Its position was last noted on the opposite (west) bank of the Elk River at 2238 h on the 10th. During the track, it covered a distance of at least 4600 m in 10 h, 42 min for a mean speed over the bottom of 0.1 m/sec.

Unusual movement patterns noted.

Betty (Fish No. 16) exhibited two distinct patterns and rates of movement. During the initial phase, her movements were very slow with periods of back and forth movement within a small area. The path of her track was confined to the vicinity of ship channel. The net movement direction (through several current reversals) was very slowly westward.

The second phase of her behavior, e.g., rapid westward movement, began during a steady tidal current state and almost (4 h) before darkness. Her change in behavior was not correlated with any external stimulus which was noted by the observers. This track was the first in which several fish were tracked simultaneously. Two males, Albert and Charley, and one female, Betty, were tagged with transmitters of the same carrier frequency but with different pulse repetition rates, e.g., 30,182, and 78 pulses/min, respectively. The pulse rep. rates were easy to differentiate under field conditions. Some trackers reported that the 78 pulses/min tag was the easiest signal to track.

In practice, the simultaneous tracking of several transmitters can be accomplished only when all of the units are within range of the tracking gear. If they become spatially separated, the tracking crew must move from one location to another noting times and positions of the various targets. Inherent in this technique is the danger that a tagged fish will move to a distant location between ovservations or that because of bottom topography or accoustic interference, the signal range will be reduced, preventing the tracking team from relocating a nearby transmitter.

The result of either situation is that the fish is lost. Sometimes the signal is relocated, as happened with Charley when he was found on the west bank of the Elk. We were not so lucky with Albert even though a grid search pattern was set up and executed.

Many field experiences with ultrasonic transmitters have led some workers to feel that transmission range in shallow water, especially areas with multicellular vegetation, is highly variable but generally much reduced from vegetation-free deeper water.

SONIC TAGGING ACTIVITIES 1973

CBL/CMS Cooperative Fieldwork

Between 1 May 73 and 7 May 73, four American shad were tagged with 74 kH_z ultrasonic tags and with Peterson disc tags and released in the Delaware River estuary. A fifth fish was tagged but, due to its poor condition, was not released. Fish were captured, tagged, and released in the shallow-water zone between Reedy Island and the Delaware shore near Port Penn and Augustine Beach.

Fish were captured by a commercial drift gillnetter under contract to the College of Marine Studies, University of Delaware. Coincidentally, with the shad sonic tracking study, a Peterson disc tagging program for several species was underway. The gillnetter and a tagger watched the corks for evidence of a fish in the net (a single net was fished) and retrieved and tagged the fish very soon after it became trapped. . An additional boat with the sonic tracking crew and equipment stood by and inserted a UST in suitable shad which were immediately released and tracked.

The overall plan was to track from the outboard boats during the day while the R/V WOLVERINE conducted trawling operations. This plan was negated by the mechanical breakdown of the R/V WOLVERINE during most of the tracking effort. Sonic tracking was thus limited to single-day, daylight-only periods.

In several instances in this tracking season, the tracking was compromised by greatly reduced signal strength and range. Several possibilities exist in explanation:

1. Inexperience in operating the receiving equipment. This must be considered for some team members but others, Wilson and Gray are very familiar with the technique and also had trouble with range

of the UST's. Both commercial and noncommercial UST's suffered reduced range in fish and in separate range checks.

2. Aging batteries definitely would have been a factor if the tracks went on for many days but my lab tests indicate that the transmitters should have operated with acceptable output for at least 5 or 6 da.

3. Water quality or vegetation in the shallows contributing to acoustic absorption. Experience in the field made me consider this possibility. This concern was reinforced by conversations with Mr. James Friedersdorf of NOAA who found similar severe range restrictions in the same area.

4. Damage to the transducer crystal due to rough handling. This is very likely the cause of at least one track failure. I inadvertently discovered late that shock can damage the acoustical output of the transducer and yet the unit can produce a deceptively strong signal at close range. The effect is that the UST tests well in the field, but has very limited range.

5. Partial breakdown in the receiving system. Not a factor in this season's work.

Summary of Tracking Efforts 1973

73-1. 1 May, prespawning male American shad 490mm, tracked by Wilson and Gray. Fish captured and released at 0955 and moved quickly towards a creek mouth between Augustine Beach and Port Penn, where it remained stationary for 20 min. It then began moving downriver while opposing a strong flooding current. The fish continued to move downriver for the duration of the track through a current direction reversal.

Tracking was difficult in the shallow water behind Reedy Island but became easier in coincidence with deeper water. Tracking was not especially difficult in the swells encountered near Artificial Island, but the tracking crew made a deliberate effort to keep reasonably close to the fish. Reacquiring the signal from a lost track would be quite difficult in this sea state. Track was terminated by mutual decision of CMS and CBL team leaders as the fish was leaving the study area and the "mother ship" WOLVERINE was out of commission.

Track duration - 4 hr, 10 min

Track distance - 7.7 km

73-2. 1 May, prespawning male 480 mm released at 1030 h off Port Penn, tracked by CMS staff. Signal location remained fixed for 5 h and tracking crew terminated the track, believing that the UST had been regurgitated. This same fish was relocated at 1105 h on 2 May by Wilson and Tom Meyers at a position 1.2 km of its release point. Various other trackers were brought to the site to gain additional experience in tracking a UST. Later, on 2 May, this UST could not be picked up at the second location. Subsequent searching did not find it.

73-3. 2 May, 321 prespawned female 455mm. Tagged and released between Port Penn and Canadas Beach. Tracked by CMS staff. Moved south (downriver) very slowly for 2 h, signal lost near Augustine Beach.

Track duration - 2 h

Track distance - 0.8 km

73-4. 7 May, male, prespawning 415 mm S/N 309. Tagged and released near Port Penn at 0930 h. No signal from UST in the water, even though the UST had been field-tested several times that day. Tracked by Wilson and CMS student.

73-5. 7 May, female prespawning. Tagged, but not released. Fish in poor condition. This fish was dissected and photographed.

Behavior observed in 12 striped bass

Net avoidance was demonstrated in a very clearcut manner by two fish. These individual fish approached stake gillnets and either made lateral movements and passed by the net or remained stationary until the net was lifted out of the water. One fish, in 1971, passed over 3 drift gillnets in the Canal. It is not known whether this fish was actively avoiding the nets which are fished near the bottom or simply swam at a net-free depth by chance. Net avoidance was observed in 67% of the three possible cases.

Distinct behavioral difference in the presence of a large shadow was positively observed in one instance during the simultaneous track of two fish. These large, prespawned females approached the shadow of the Summit Bridge near noon on a clear day and one fish hesitated at the edge of the bridge's shadow for over an hour. The other fish was not observed to change pace in the vicinity of the bridge. It is perhaps meaningless to offer a percentage of observed vs. possible shadow avoidance reactions, as light intensities were not quantified during this study. It is interesting to note that the two fishes of the same species, sex, and similar spawning condition displayed such a different behavior in the presence of the shadow.

Swimming near the shoreline vs. the mid-channel area, especially when facing a current flow, was demonstrated by most of 11 (73%) fishes during some of the observation period. Fish that were swimming with a current flow did not demonstrate a clear position preference.

Eight fish were much more frequently located out of the channel. Two fish (18%) were found in or near the channel and one fish (8%) displayed varying preference but finally left the study area via a deepwater midchannel route. Six fish were not observed for this characteristic (shore-monitor tags).

Within the group that preferred proximity to the shoreline, the three fishes observed for the longest periods of time demonstrated the greatest preference. Fish 5, a post-spawned female tracked in May 1971, remained within 10 m of the bank for most of the hours of daylight for the 4 d of constant observation. Even during her nocturnal movements, a definite shore-zone preference was indicated. Fish 14, tracked in 1972, again a large, prespawned female, swam near the north bank from close to the release point to a position near the old railroad cut and while this fish roamed slowly within a 2.5 km long region between the railroad bridge and Summit Bridge, the movement was restricted to the 10-15 m nearest the bank. Fish 12 also preferred the shore zone but since this fish was observed in addition to fish 14 during the same period, its movements were not as precisely charted.

A marked difference in day-night behavior was observed in the behavior of fish 5, but not to the same degree in any other tracked fish. This post-spawned female remained cirtually stationary during the day and made nocturnal excursions within a 6.5 km section of the Canal. No other fish tracked exhibited such a clear diel behavior pattern. Fish 14's behavior pattern contained periods when the fish was stationary for up to two hours, but a more general observation was that the fish was moving at various slow speeds to and fro along a 2.5 km segment of the north bank of the Canal.

Change in behavior with respect to change in current conditions was observed in all fishes whose period of observation lasted through a slack tide or tidal current reversal. Some fishes apparently took refuge from adverse current directions and velocities by moving into eddies or slower currents near shore and when currents slackened and reversed direction, distinct behavioral changes were noted. Fishes were observed to hold a position during current flow in one direction and, when the flow began in

the opposite direction, to move with it or sometimes against it, but the change in tidal current seemed to be the stimulus.

The passage of large vessels, even in the restricted area of the Canal, had no observable effect on the behavior of most fish. A few instances of a shift in the tracked fishes position was noted in 1971, but no repetition of this reaction was observed in 1972. In 1971, many vessels passed which did not cause startle or fright reactions in the same fish which at other times responded to this type of disturbance. At all times, the tracking crew attempted to maintain a separation distance of at least 100 m, especially when the tracking boat's engine was running.

The observations of 12 fishes cannot form the basis for hard and fast conclusions, but coupled with information for other phases of this same overall study and other data have led me to the formulation of a working hypothesis concerning striped bass migration patterns in the Elk River, Chesapeake and Delaware Canal.

Beginning in March, sexually maturing striped bass in prespawning-ripening condition approach the Elk River, Chesapeake and Delaware Canal system from both the Chesapeake and the Delaware Bays. The relative contribution of the two systems is not fully quantified but the commercial landings and other evidence indicate that the great majority come from the Chesapeake Bay.

On the Chesapeake side, the abundance is greatest at the mouth of the Elk River, at first. The region of greatest abundance gradually moves toward and into the Canal itself. Prior to spawning, individual prespawn-fish move extensively throughout the system. Some fishes transit the Canal, pass into the Delaware River, and then return to the Chesapeake Bay via the same C and D Canal. Others move out into Chesapeake Bay and then return. The peak of spawning activity takes place during a two-week period

at the end of April -- the beginning of May. Fish remain in the system for several days or move after spawning, probably resting, since movement records contain long periods with no change in position. Post-spawned striped bass then migrate out of the Canal into both the Chesapeake Bay and the Delaware River.

Results - The Effects of Currents on Fish

One of the major effects of the Canal enlargement is the increase in current velocity. Pritchard and Cronin (1971) state that the average maximum tidal velocities and the mean tidal velocity will be increased by a factor of 1.23 or 23%. Table 4 shows the relationship of velocities in the 27 ft deep, 250 ft wide, and 35 ft x 450 ft Canal. The average maximum tidal velocity is shown to be 3.57 ft/sec or 1.09 meter/sec during an eastward flow for the enlarged Canal and an average maximum tidal velocity of 2.90 ft/sec (.88 m/sec) for the unaltered 27 ft by 250 ft waterway. The westward flow figures are 2.80 ft/sec (.85 m/sec) (35 x 450) and 2.28 ft/sec (.7 m/sec) (27 x 250).

The NOAA Tidal Current Tables for 1958 through 1972 report an average maximum current velocity at Reedy Point Bridge of 4.42 ft/sec (1.34 meter/sec) eastward flow and 3.38 ft/sec (1.03 m/sec) eastward flow at Chesapeake City Bridge. The entrance to Back Creek is shown to have an average maximum tidal velocity of 1.7 ft/sec (.51 m/sec). The mean velocity of these three stations in the Canal is 3.15 ft/sec (1.06 m/sec) which is not greatly dissimilar from Pritchard's 1971 report of Wickers' 1938 study of the hydraulics of the Canal.

Table 4 shows that the eastward flow is the strongest, the westward flow toward the Chesapeake Bay the weaker, and also that the average maximum current velocity increases towards the eastern (Delaware) end of the Canal. Current velocities in the Elk River portion of the study area are much reduced from those in the dug Canal.

Table 4. Tidal velocities

Average maximum tidal velocities in the Chesapeake and Delaware Canal*

	27 ft x 250 ft		35 ft x 450 ft	
Eastward	2.9 ft/sec	(.88 m/sec)	3.57 ft/sec	(1.09 m/sec)
Westward	2.28 ft/sec	(.7 m/sec)	2.80 ft/sec	(.85 m/sec)

Average maximum tidal velocities at three locations in the Chesapeake and Delaware Canal+

	Back Creek Entrance	Ches. City Bridge	Reedy Pt. Bridge
Eastward	1.7 ft/sec (.5 m/sec)	3.4 ft/sec (1.0 m/sec)	4.4 ft/sec (1.3 m/sec)
Westward	2.0 ft/sec (.6 m/sec)	3.2 ft/sec (1.0 m/sec)	3.5 ft/sec (1.1 m/sec)

* Pritchard and Cronin, 1971

+ NOAA Tidal Current Tables, 1972

Table 4 indicates that fishes entering the dug Canal from the Chesapeake must swim against currents with an average maximum velocity of 0.6 m/sec, increasing to 1.1 meter/sec at the Delaware end of the Canal. A 23% increase in these velocities would give currents of .7 and 1.4 meters/sec. Do currents of such velocities represent a barrier to the passage of fishes?

Many studies have been conducted to determine the maximum swimming speeds of various species of fish (Stringham, 1924; Wales, 1950; Gray, 1953; Paulick and DeLacy, 1957; Bainbridge, 1958, 1960, 1962; Blaxter and Dickson, 1959; Boyar, 1961; Brett, 1964). Studies of the cruising speeds were undertaken by Magnan, 1930; Fry and Hart, 1948; Davidson, 1949; Radcliff, 1950; Paulich and DeLacy, 1958; Brett, Hollands, and Alderice, 1958. These studies indicate that the size (length) of fishes is a determinant of the speed which can be attained and maintained. Fishes can achieve speeds of the order of 10 body lengths per second for a very short time, 1-2 seconds, but can swim at 3 lengths/sec for long periods (Bainbridge, 1960; Brett, 1964). Boyer (1961) notes that swimming endurance is dependent upon length and water velocity. As the velocity increases, swimming endurance for a particular length-class decreases. As the fish-size increases, its swimming endurance at a particular water velocity increases.

Figure 8 presents a generalized swimming endurance curve. Below 3 lengths/sec, the curve quickly becomes asymptotic for time or endurance. Bainbridge (1958) studied trout which had been swimming continuously at a cruising speed of from 1.0 to 1.5 lengths/sec for exactly one year. Large fishes can cruise at speeds which are greater than the cruising speed of small fishes.

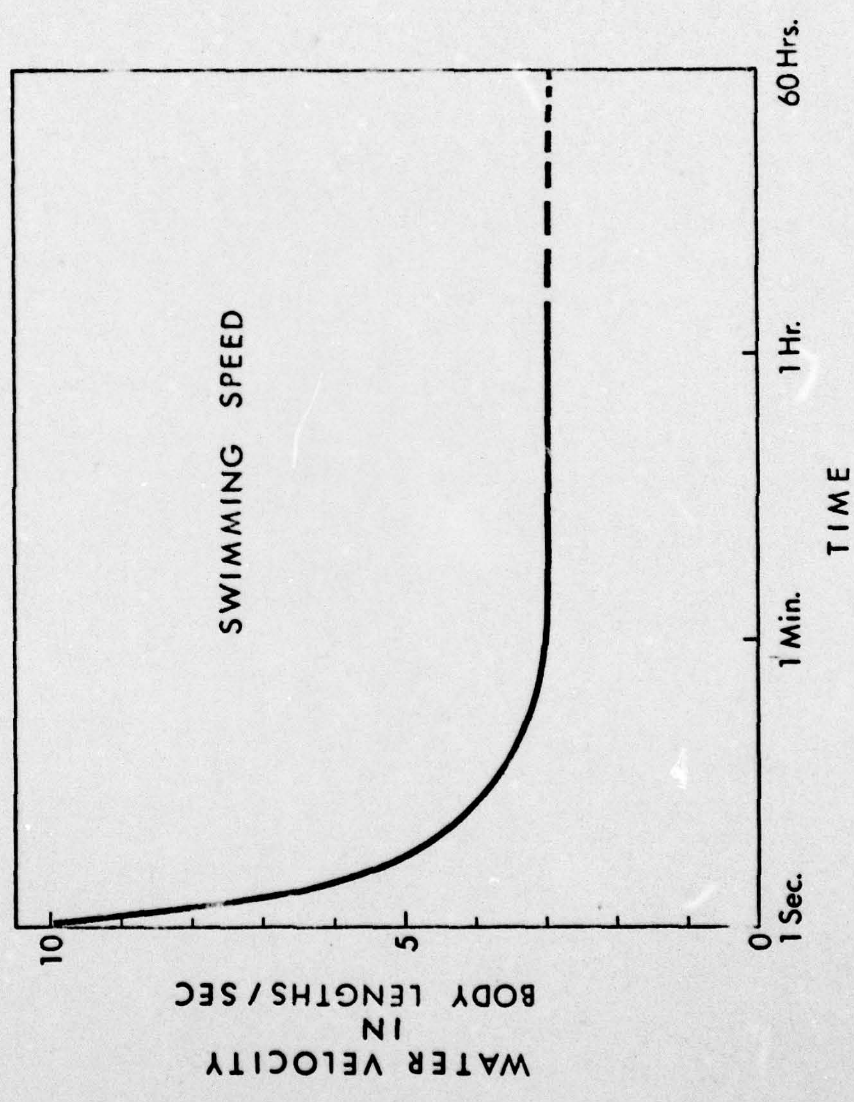

SWIMMING SPEED
WATER VELOCITY IN BODY LENGTHS / SEC
10
5
0
1 Sec.
1 Min.
1 Hr.
60 Hrs.
TIME

FIGURE 8

Raney (1952) reports that almost all male striped bass (23 cm or more in length) were found to be sexually mature and capable of spawning. In females of this species, 25% of the 46 cm in length fish and 83% of 56 cm length fish were mature spawning fish. For male striped bass, with an assumed cruising speed capability of 3 body-lengths per second, a water velocity above .84 m/sec would prevent progress over the bottom, therefore

11" (.916) ft or 28 cm x 3 = 2.75 f/sec (.84 m/sec)

For females of 22: or 56 cm length, a current velocity of 5.50 ft/sec (1.68 m/sec) would be similarly limiting, namely

1.83 ft 22 x 3 = 5.5 ft/sec or 1.68 m/sec

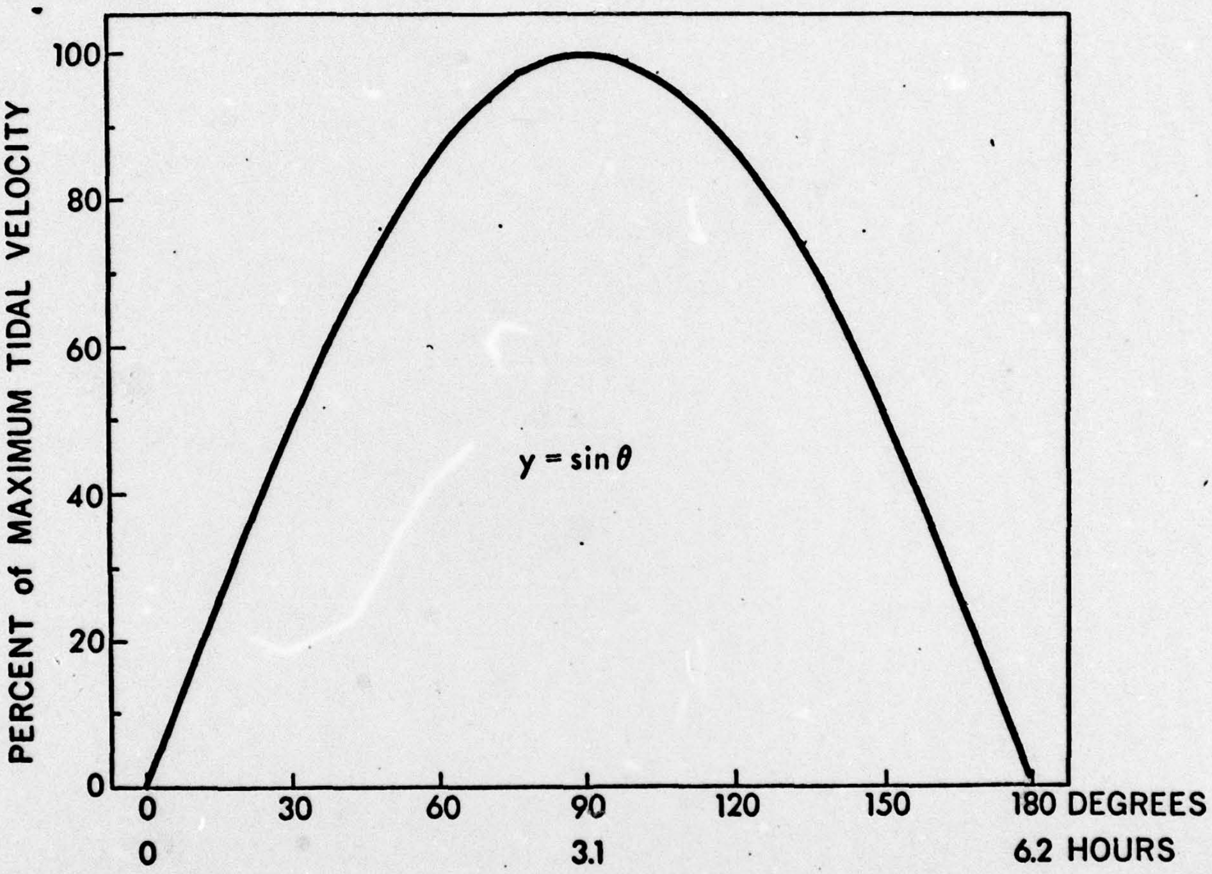
Assuming a 3 ft/sec swimming speed capability, the data in Table 5 indicates that 23.3 cm or 11" striped bass could pass into the Canal from the Chesapeake at will, would be hindered from passing under the Chesapeake City Bridge in mid-channel at the surface for 2 h, 16 min, of the 12.42 h tidal period during the peak of a westward flow and at Reedy Point Bridge for 2 h, 51 min, at the same tidal stage. A 56 cm or 22" female with a cruising speed of 1.68 m/sec would not be barred from transiting the Canal by water currents.

The presently existing currents in the Canal, if of sufficient duration, represent a real, if short-term, barrier to the unimpeded passage of some smaller sizes of fishes. An increase in velocity would increase the length of fish excluded, however, the effectiveness of such a velocity barrier in a system like the Canal is reduced by the cyclical nature of these currents and adaptive fish behavior.

Most tidal current patterns may be represented by a sinusoidal wave. In the Canal, this is true for the western end to a greater degree than for the eastern, Delaware end(Pritchard and Cronin, 1971). Table 5 is derived from Figure 9, a general sine function ($y = \sin x$) and displays the percentage of time during a tidal cycle when selected current velocities may be expected. The percentages and times refer to the duration of currents in one direction in the Canal, either eastward or westward flow, during a 12.42 h normal tidal cycle comprising one ebb and one flood tide.

It is expected and well documented that fishes make use of current mitigating features of their habitat (Lagler, Bardack and Miller, 1962; Kendeigh, 1961).

Initial and maintenance dredging of the Canal channel is not intended and does not in practice produce an absolutely uniform bottom surface. Furthermore, large stones placed as erosion-preventing rip-rap along the edges of the Canal banks introduces more irregularities. These non-uniformities cause local turbulence and reduce the water velocity in the vicinity. Even a smooth bottom would reduce current velocities due to frictional energy loss. Eddy currents with flow direction opposite to the surface current direction in the channel are frequently observed near the Canal banks. The reported current velocities represent maxima for mid-channel surface locations, while locations adjacent to the Canal sides and bottom experience reduced velocities due to turbulence, friction and eddy currents. In actuality then, because of the cyclical nature of current direction and rate of flow, the velocity reducing features of the Canal and the ability of free-swimming fishes to seek preferred positions in their habitat, an increase in current velocity alone will not significantly alter the movement patterns of sexually mature striped bass.



PERCENT of MAXIMUM TIDAL VELOCITY
100
80
60
40
20
0
y = sin θ
0
30
60
90
120
150
180 DEGREES
0
3.1
6.2 HOURS

Figure 9.

Table 5. Velocities as a percentage of maximum velocity for a tidal cycle. Tidal period = 12.42 h.

Vel	.5 max	30°	-150°	120/180	67%
Vel	.75 max	48°30'	-131°30'	83/180	46%
Vel	.90 max	64°	-116°	52/180	29%
Vel	.95 max	72°	-108°	36/180	20%
Vel	.98 max	79°	-101°	18/180	10%
Vel	.84 max	57°	-123°	66/180	36%

				hrs min		hrs min
Vel	.5 max	67%	8.31	8:19	4.16	4:10
	.75	46%	5.71	5:43	2.86	2:52
	.90	29%	3.60	3:36	1.8	1:48
	.95	20%	2.48	2:29	1.24	1:14
	.98	10%	1.24	1:14	.62	0:37

Values for y - sin X from Arkin, H & R.R. Colton.

Tables for statisticians

Barnes & Noble 1963 N.Y.

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